SF2A 2017
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DISC KINEMATICS FROM GAIA DR1

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Abstract. The complementarity of radial velocity survey RAVE with Gaia first data release (TGAS) gives the opportunity to study the full 3D velocity space in a wide solar neighbourhoud. Using a revised version of the Besançon Galaxy Model, we simulate the kinematics of stellar populations to be compared with those new data. In modelling the kinematics, we account for the asymmetric drift computed from fitting a Stäckel potential to orbits (Bienaymé et al. 2015). We show that this model is able to reproduce the kinematics of the local discs in great detail for both the thin and thick discs. The $U_\odot$ and $W_\odot$ components of the Solar motion agree well with previous studies. However we revise significantly the previous estimates of $V_\odot$ velocity, with a value of 1 km/s, thanks to the new proper motions from Gaia, the inclusion of the variation of the asymmetric drift with distance to the plane, and to the method used where model parameters are fitted in the space of observables.

Keywords: Galaxy:evolution, Galaxy:dynamics, Galaxy:disk, Galaxy:kinematics, Galaxy: formation, Galaxy: stellar content

1 Introduction

The Gaia mission, launched in December 2013, is expected to revolutionize our view of the Milky Way, specially from the measurements of exquisite proper motions and parallaxes. Since the first data release (Gaia Collaboration et al. 2016) it has provided accurate transversial velocities for nearby stars, by combining the first months of observations, with previous Tycho-2 positions. On the other hand, The RAVE (RAdial Velocity Experiment, Kordopatis et al. 2013; Kunder et al. 2017) has provided exquisit radial velocities, with an accuracy of 1-2 km/s for a large sample of stars in a wide solar neighbourhood. This is a good opportunity to question our knowledge about the kinematics in the solar neighbourhood, at larger distances than Hipparcos allowed to do.

In this study we use a revised version of the Besançon Galaxy Model to compare with these new data sets and reconsider the velocity ellipsoids and age-velocity dispersion relations of the thin and thick disc as well as the solar motion.

2 Description of the data set

We make use of the RAVE DR4 (Kordopatis et al. 2013). The stars are randomly selected in fields covering the southern hemisphere, avoiding the Galactic plane. Hence this is a sample which is adequate for a statistical analysis of the stellar populations and their kinematics. Stars are selected from their magnitude and are all part of the Tycho-2 catalogue (Hoeg et al. 1997). In our analysis we select stars with temperatures between 4000 and 8000 K, and at latitudes $|b| > 25°$.

The Gaia first data release (TGAS)(Lindegren et al. 2016; Gaia Collaboration et al. 2016), has provided proper motions and parallaxes for stars in Tycho-2 catalogue, based on a the scheme proposed by Lindegren et al. (2016). This first release provides positions, parallaxes with an accuracy of about 1 mas and proper motions for single stars at the level of 1 mas/yr, using the first 11 months of the mission, using the positions measured 25 years ago by Tycho-2. However this first release suffers from some systematics, depending on the number of time the star has been observed, which varies with sky position. This is for this reason, and because

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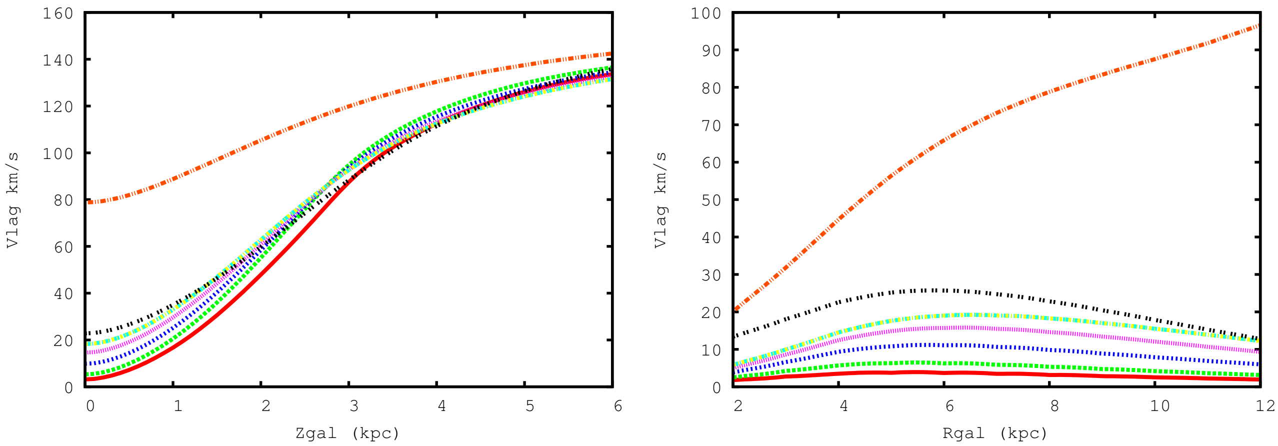

Fig. 1. Asymmetric drift computed from the Stäckel approximation of the BGM for subcomponents 2 to 7 (thin disk, with increasing ages plotted in solid red, long dashed green, short dashed blue, dotted magenta, dashed yellow and cyan), and for the young (dot-dashed black) and old (dot-dot-dashed red) thick disks. **Left panel:** as a function of $R_{\rm gal}$ for $z_{\rm gal}$=0; right panel: as a function of $z_{\rm gal}$ for $R = R_{\odot}$.

the accuracy is limited to stars within a small solar neighbourhood, that we choose in this study not to use the parallax information, but only the proper motions.

We analyse the combined sample RAVE+GaiaDR1 (TGAS) by comparison of these data with model simulations which are provided by the Besançon Galaxy Model, as described below, in the space of observables (magnitude, metallicity, radial velocity, proper motions).

3 The Besançon Galaxy Model

In this study we use the version of the model described in Czekaj et al. (2014) where the stars are drawn from chosen initial mass function and star formation rate for the thin disc population. This scheme takes into account the expected binary fraction, mass ratio and semi-major axis distributions as seen in observations, as described in Arenou (2011). The thin disc population is modeled by the sum of 7 sub-populations of different ages, assumed to be each isothermal. The metallicity is also a function of age (Haywood 2008). The Galactic potential is computed from the mass distributions of the stellar populations, where the interstellar matter and dark halo are added up (Robin et al. 2003). In Bienaymé et al. (2015) this potential has been approximated by a Stäckel potential, which allows to compute the third integral of motions and self-consistent analytical solutions for the distribution functions. This method is used to compute the exact value of the asymmetric drift and its variation with R and z for each isothermal sub-population. Figure 1 show the variations of the asymmetric drift as a function of Galactocentric cylindrical coordinates. For simplicity for the time being, the densities are Einasto laws, as in previous models (Robin et al. 2003).

In this model, the thick disc is modelled as described in Robin et al. (2014), that is a sum of two episodes of formation, at 10 Gyr ago (the young thick disc) and 12 Gyr (old thick disc). These two components have different density distributions on the sky, the young thick disc being more concentrated to the Galactic center and the Galactic plane (see Robin et al. 2014, for details).

We attempted to define the kinematics of the thick disc in this study, trying to see whether the contraction of the thick disc with time (from the old to the young, as found previously) was also seen in their kinematics, expecting the velocity dispersion of the young component to be smaller than the older one.

To test the sensitivity of the data to the choice of a given rotation curve, we consider alternatively Caldwell & Ostriker (1981) and Sofue (2015) rotation curves.

4 Model fitting method and results

The ABC-MCMC scheme was used to determine the free parameters of the model. Namely : the solar motion, the age-velocity dispersion V_z of the thin disc, and the ratios V_z/V_x and V_y/V_z assumed not varying with time, the full velocity ellipsoid for the young and old thick discs, a vertex deviation depending linearly on age. To evaluate each model, the goodness-of-fit parameter was the one used by Bienaymé et al. (1987). An ABC (Approximate Bayesian Computation) method allowed to compute the likelihood for each model realization, because it is not possible to compute an analytic bayesian probability distribution function for our complex model.

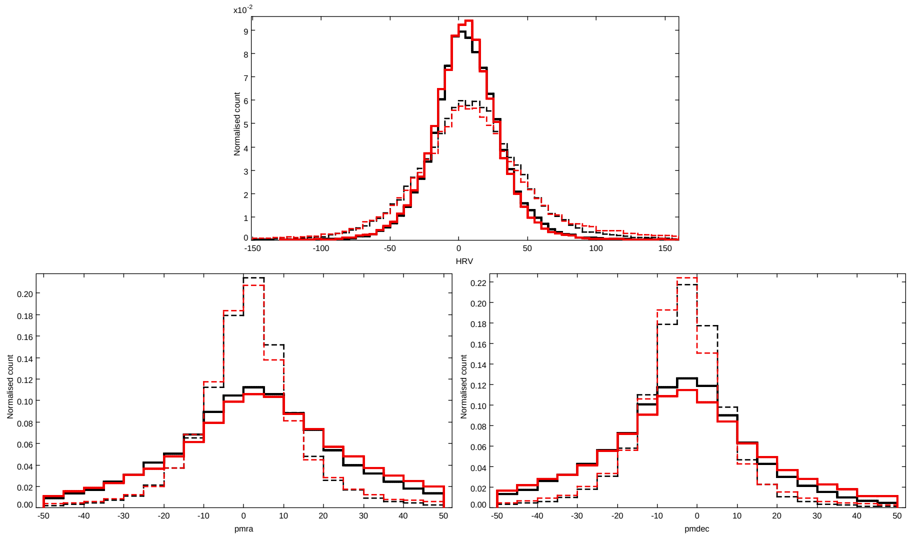

Fig. 2. Histograms of RAVE radial velocity distributions, and proper motions from Gaia DR1, for hot (solid lines) and cool (dashed lines) stars. Data are shown as black lines, and the best-fit model is shown as red lines.

The ABC-MCMC algorithm, using the Metropolis-Hasting sampling, was used in 15 independent runs of 200,000 iterations each. We checked the correlations between parameters in the solutions, and that the standard deviation in each run was compatible between independent runs. Table 1 shows the resulting model parameters obtained by averaging the solutions of different runs, together with the uncertainties, assuming that the variation of the σ_W with age in Gyr follows a polynomial of coefficients A,B,C.

5 Conclusions

The complementarity of the RAVE radial velocities with the Gaia proper motions gives a unique opportunity to trace and characterize the kinematics in a wide solar neighbourhood. The sample is much larger than the ones used in previous studies, such as the Geneva-Copenhaguen survey, used in Schönrich et al. (2010), and the accuracies and precisions are incomparable. Hence, we believe that our results are more robust that previous ones. We determined the variation of the velocity ellipsoid of the thin disc as a function of time, which we find in good agreement with Gómez et al. (1997) and with the model of Bovy et al. (2012); the velocity ellipsoid of the thick disc is shown to also vary with time, with the young thick disc having a lower velocity dispersion than the old thick disc, in agreement with our scenario of contraction during the thick disc episode (Robin et al. 2014).

We find the Solar motion to be U, V, W=(12.75,0.93,7.10) km/s slightly different from previous studies, probably due to the fact that we account for the variations of the asymmetric drift with position from the Galactic plane, that we fit in the observable parameter space, avoiding biases introduced by the inversion method, thanks to the exquisite precisions of Gaia data.

The new model can be used for simulations at this address: `http://model2016.obs-besancon.fr/`. It is also available through a web service, for automatic uses and downloads from workflows.

BGM simulations were executed on computers from the Utinam Institute of Université de Franche-Comté, supported by the Région de Franche-Comté. This study was supported by Programme National Cosmologie et Galaxies (PNCG) and INSU. JGFT acknowledges the support from CNES (Centre National d'Etudes Spatiales) and Région de Franche-Comté. We acknowledge the use of the *RAVE* survey (`https://www.rave-survey.org`). This work has made use of data from the European Space Agency (ESA) mission *Gaia* (`https://www.cosmos.esa.int/gaia`), processed by the *Gaia* Data Processing and Analysis Consortium (DPAC,

Table 1. Best values of fitted parameters obtained by the mean of the last third of eight independent chains and standard deviation assuming Caldwell & Ostriker (1981) and Sofue (2015) rotation curves. Units are km/s for velocities, pc for the scale lengths, and radians for the vertex deviation, which is given for stars younger than 1 Gyr (VD_a) and older than 1 Gyr (VD_b). A, B, and C are the coefficients of the polynomial describing the variation of σ_W with age in Gyr.

Parameter	Caldwell	Sofue
Solar motion		
$U_\odot$	12.75 ± 1.26	11.88± 1.38
$V_\odot$	0.93 ± 0.30	0.91± 0.26
$W_\odot$	7.10 ± 0.16	7.07± 0.16
Thin disk		
A	5.69 ± 0.37	5.69± 0.41
B	2.48 ± 0.30	2.33± 0.28
C	−0.0966 ± 0.0404	−0.0774± 0.0362
σ_V/σ_U	0.57 ± 0.03	0.58± 0.03
σ_W/σ_U	0.46 ± 0.03	0.46± 0.02
h_{σ_U}	13176. ± 6908.	9534.± 3982.
h_{σ_W}	15919. ± 8609.	10414.± 6299.
Thick disk		
σ_U	40.02 ± 1.74	41.58± 1.51
σ_V	31.86 ± 1.55	30.95± 1.50
σ_W	27.89 ± 1.26	27.02± 1.00
Old thick disk		
σ_U	75.64 ± 8.58	79.64± 7.96
σ_V	55.41 ± 8.74	57.55± 8.51
σ_W	66.43 ± 3.95	62.15± 6.62

`https://www.cosmos.esa.int/web/gaia/dpac/consortium`). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the *Gaia* Multilateral Agreement.

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