Rediscovering our Galaxy
Proceedings IAU Symposium No. 334, 2017
C. Chiappini, I. Minchev, E. Starkenburg
& M. Valentini, eds.

doi:10.1017/S174392131700669X

Kinematics of the Milky Way disc from the RAVE survey combined with Gaia DR1

Annie C. Robin[1], **Olivier Bienaymé**[2], **José G. Fernández-Trincado**[1] **and Céline Reylé**[1]

[1]Institut Utinam, CNRS UMR6213, Univ. Bourgogne Franche-Comté, OSU THETA ,
Observatoire de Besançon, BP 1615, 25010 Besançon Cedex, France
email: `annie.robin@obs-besancon.fr`

[2]Observatoire Astronomique de Strasbourg, Université de Strasbourg, CNRS, 11 rue de l'Université, F-67000 Strasbourg, France
email: `olivier.bienayme@astro.unistra.fr`

Abstract. Relying on the complementarity of Gaia proper motions with radial velocities of the RAVE survey, we attempt to constrain the kinematics of the Milky Way disc. Based on the population synthesis model, we simulate the observations, applying the detailed selection functions of the observations. The dynamics is described using a global gravitational potential computed from the mass distribution of the population model, approximated by a Stäckel potential (Bienaymé *et al.* 2015). We explore a set of free parameters (solar motion, age - velocity dispersion of the disc as a function of age, the velocity gradients, vertex deviation) using a Markov Chain Monte Carlo method. We show that the fitted model reproduces very well the radial velocity and proper motion distributions, allowing to constrain the thin and thick disc secular evolution with time.

Keywords. Galaxy:evolution, Galaxy:dynamics, Galaxy:kinematics, Galaxy: stellar content

1. Introduction

The Gaia mission is planned to revolutionize our vision of the Milky Way formation and evolution. One important aspect of the expected results concerns its dynamics which is directly related to the overall distribution of matter and in particular the dark matter. In order to determine the part of the mass residing in dark matter it is important to well understand first the bright matter, most residing in stars. Gaia will enable such an inventory. Second, Gaia will observe the kinematics of the diverse populations, allowing to derive constraints on the overall potential. Hence, new tools have to be developed in order to fully exploit those two aspects of the Gaia mission.

In order to prepare the future Gaia exploitation, we use the population synthesis approach, which allows to consistently study the distributions of light and matter in the Milky Way (Crézé & Robin, 1983). The method allows to simulate data sets and to compare predictions with observations, taking into account the survey selection function, in the space of observables. The method is based on simple realistic assumptions for different populations and constrained by the Boltzmann equation (Bienaymé *et al.* 1987).

In Bienaymé *et al.* (2015) we described how a Stäckel potential can be fitted to the Besançon Galaxy model potential in order to simplify the computation of algebraic solutions for the distribution functions. In this paper, the asymmetric drift was computed for the different disc subcomponents on the model, assuming an age-velocity dispersion relation. Here we consider these computations to compare with observed kinematics in the solar neighbourhoud.

The method makes use of the latest version of the Besançon Galaxy Model, hereafter BGM (Robin *et al.* 2014, Czekaj *et al.* 2014) and is applied on the RAVE survey (DR4, Kordopatis *et al.* 2014) and proper motions from TGAS-Gaia DR1 (Brown *et al.* 2016) in order to constrain the kinematics. The model is described in section 2, while the ABC-MCMC fitting method, used to adjust the model parameters in the space of observables of the survey data is presented in Sect. 3. Discussion and conclusions are given in Sect. 4.

2. The Besançon Galaxy Model potential

The Besançon Galaxy Model, hereafter BGM has been renewed recently to take into account many new large scale survey data providing new constraints on Galactic evolution scenarios. Our studies conducted to revise the density laws, age and metallicity distributions of the thick disc and the stellar halo were described in Robin *et al.* (2014). In parallel, we revised the thin disc evolution parameters, the Initial Mass Function and Star Formation History in Czekaj *et al.* (2014), where the scheme of the computation was completely revised and the binarity was taken into account. This new procedure leads to better fit to the solar neighbourhoud stellar content, in particular by comparison with the Tycho-2 survey.

Based on these new results, Bienaymé *et al.* (2015) fitted a Stäckel potential on the potential computed from the mass distribution of the BGM, allowing to compute approximate third integrals of motions for disc stars. Then the axisymmetric drift has been computed for the disc subcomponents as functions of Galactocentric radius and distance from the plane, and introduced into the population synthesis model, allowing to provide self-consistent kinematic prescriptions.

3. ABC-MCMC fitting method

For testing the resulting model, we simulated the RAVE survey (Kordopatis *et al.* 2013), accounting for the survey selection function, and combining it with the proper motions from TGAS (Brown *et al.* 2016). The latter is not complete to the limiting magnitude of RAVE (approx. 11.5). Hence we restricted the analysis to magnitude 11.5 for RAVE radial velocities and 10.5 for TGAS proper motions. We also considered stars with reliable effective temperature in the range $4000 < T_{\rm eff} < 8000$ K.

We used the effective temperature to statistically distinguish dwarfs from giants, a parameter which suffers less from systematics than the gravity. Finally we bin stars according to their metallicities in order to ease the separation between the metal-rich thin disc, the solar-metallicity thin disc, the normal thick disc, and the metal-weak thick disc.

Data where binned into 11 fields according to their longitude and latitude, then radial velocity (resp. proper motion) histograms from the model were compared with RAVE (resp. TGAS) data, and the goodness of fit estimated using a reduced likelihood.

Fitted model parameters were : the 3 components of the solar motion, the age-velocity dispersion relation σ_W for the thin disc, the ratios σ_U/σ_V and σ_U/σ_W, the vertex deviation, the radial kinematical scale lengths h_{σ_U} and h_{σ_W}, and the velocity ellipsoid components for the two components of the thick disc (see Robin *et al.* (2017) for details).

We chose the ABC-MCMC technique, Approximate Bayesian Computation Markov Chain Monte Carlo (Marin *et al.* 2011), to find the best solution, as well as the range of solutions compatible with the data, and their correlations. Figure 1 presents the resulting age-velocity dispersion relation for the thin disc, compared with previous results. We find a very good agreement with Gomez *et al.* (1997) values derived from Hipparcos data, as well as with Bovy *et al.* (2012) from the APOGEE spectroscopic survey data.

https://doi.org/10.1017/S174392131700669X Published online by Cambridge University Press

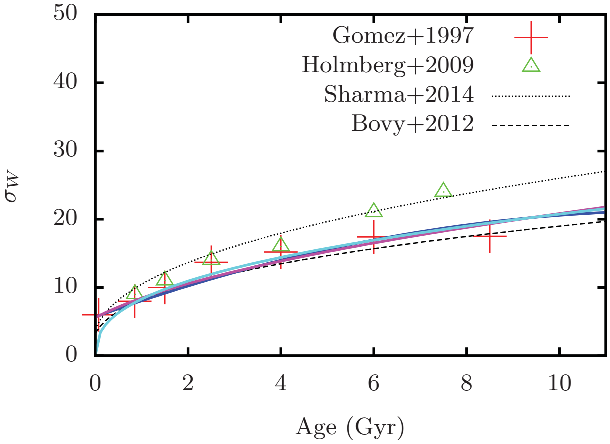

Figure 1. Evolution of the vertical velocity dispersion of the thin disc with age. Solid lines: best-fit solutions; symbols: Gomez *et al.* (1997) values from Hipparcos (red plus), Holmberg *et al.* (2009) (green triangles). Dotted line: Sharma *et al.* (2014). Dashed line: Bovy *et al.* (2012).

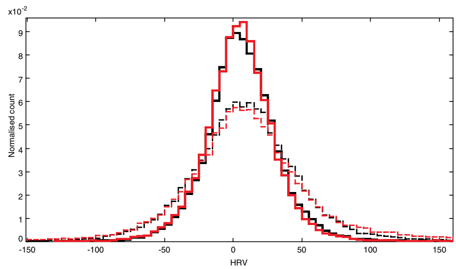

Figure 2. Histograms of RAVE radial velocity distributions for hot (solid lines) and cool (dashed lines) stars. Data are shown as black lines, and the best-fit model is shown as red lines.

We present in Figure 2 histograms of radial velocities, comparing the best model with data for hot (dwarf) stars and cool (giant) stars of the RAVE data. The overall agreement of the model is very good, even if very slight discrepancies exist in some fields, probably due to non-axisymmetries not taken into account in the model.

4. Discussion and conclusions

We confirm the saturation of the age-vertical velocity dispersion relation at a value around 21 km/s for the old thick disc. Our results confirm previously known secular evolution of the thin disc. We find the thick disc to have values going from 28 km/s for the young thick disc to 66 km/s for the old thick disc, confirming the collapse of the thick disc during its formation (see Robin *et al.* (2014) for details of this scenario). We find U and W components of the solar motion in very good agreement with previous studies. However, we find a lower value of the V component, of 1 km/s. Literature values cover values in the range 3 to 26 km/s. Among the most recent studies, Binney *et al.* (2010) study based on GCS and SDSS data points toward 11 km/s, Schonrich *et al.* (2010) also from GCS toward 12.24± 0.5 km/s, but with a sensitively different model. On the lower side limit, Aumer & Binney (2009) used Hipparcos data and found $V_\odot$ = 5.25± 0.54 km/s, while Bovy *et al.* (2012), using preliminary APOGEE data (first year release), obtained 26±3 km/s, but with a high value of $V_{LSR} + V_\odot$ =242 km/s. The large discrepancies observed

https://doi.org/10.1017/S174392131700669X Published online by Cambridge University Press

are due to several factors. Notably, the values depend strongly on the characteristics of the observed samples. Moreover, in many determinations, the kinematical assumptions are crude and do not account for the dependency of the asymmetric drift with position in the Galaxy and height above the plane. However in the studies conducted by Binney *et al.* (2010) and subsequent works (Binney *et al.* 2012, 2014), detailed and self-consistent kinematical models are used and the derived values of $V_\odot$ are still larger than ours.

To explain our lower value, we claim that it is due mainly to two reasons which distinguish both approaches: First, we use for the first time the TGAS sample, a brand new data set which is expected to provide the best proper motions available (before the Gaia future releases) without any (or very little) systematic errors which are known to be present in the UCAC4 used by other authors. Second, we do not fit the data set in the real space of coordinates, which would require accurate and unbiased estimates of the distances to the stars, but instead we fit the model directly in the space of observables, i.e. on radial velocities and proper motions.

Future releases of the Gaia space mission are expected to provide even more accurate proper motions, as well as parallaxes for a wide part of the Milky Way. We expect that our result can be confirmed or infirmed in a near future using Gaia and complementary spectroscopic surveys, and our knowledge of the disc kinematics to be extended to several kiloparsecs, giving an opportunity to determine better the Galactic potential on a wide Galactic scale.

Acknowledgements

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, `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.

References

Bienaymé, O., Robin, A. C., & Crézé, M. 1987, *A&A*, 180, 94
Bienaymé, O., Robin, A. C., & Famaey, B. 2015, *A&A*, 581, A123
Bovy, J., Allende Prieto, C., Beers, T. C., *et al.* 2012, *ApJ*, 759, 131
Gaia Collaboration, Brown, A. G. A., Vallenari, A., *et al.* 2016, *A&A* 595, A2
Crézé, M. & Robin, A. 1983, in IAU Colloq. 76: Nearby Stars and the Stellar Luminosity Function, ed. A. G. D. Philip & A. R. Upgren, Vol. 76, 391
Czekaj, M. A., Robin, A. C., Figueras, F., Luri, X., & Haywood, M. 2014, *A&A*, 564, A102
Gaia Collaboration, Brown, A. G. A., Vallenari, A., *et al.* 2016, *A&A*, 595, A2
Gomez, A. E., *et al.* 1997, in ESA Special Publication, Vol. 402, Hipparcos - Venice '97, 621–624
Holmberg, J., Nordström, B., & Andersen, J. 2009, *A&A*, 501, 941
Kordopatis, G., Gilmore, G., Steinmetz, M., *et al.* 2013, *AJ*, 146, 134
Marin, J., Pudlo, P., Robert, C., & Ryder, R. 2011, *Statistics and Computing*, 1
Robin, A. C., Reylé, C., Fliri, J., *et al.* 2014, *A&A*, 569, A13
Robin, A. C., Bienaymé, O., Fernández-Trincado, J. G., & Reylé, C. 2017, *A&A*, astroph.1704.06274
Sharma, S., Bland-Hawthorn, J., Johnston, K. V., & Binney, J. 2011, *ApJ*, 730, 3

https://doi.org/10.1017/S174392131700669X Published online by Cambridge University Press