SF2A 2008
C. Charbonnel, F. Combes and R. Samadi (eds)

GALACTIC KINEMATICS FROM RAVE TO GAIA-RVS DATA

Veltz, L.[1], Bienaymé, O.[2], Steinmetz, M.[1], Zwitter, T.[3], Watson, F. G.[4], Binney, J.[5], Bland-Hawthorn, J.[6], Campbell, R..[1], Freeman, K. C.[7], Gibson, B.[8], Gilmore, G.[9], Grebel, E. K.[10], Helmi, A.[11], Munari, U.[12], Navarro, J. F.[13], Parker, Q. A.[14], Seabroke, G.[15], Siebert, A.[2], Siviero, A.[12,1], Williams, M.[1] and Wyse, R. F. G.[16]

Abstract. RAVE data has provided new results on Galactic kinematics like the kinematical decomposition of the Galactic disk. This decomposition permits to identify the different components of the disk and to characterize them in terms of scale height and scale length. With the data provided by Gaia and in particular the RVS, we will have a completly renewed view of the Galaxy. The precision of the RVS will permit to undertake a precise analysis of the kinematics of the Galactic disks. This knowledge will provide significant clues to constrain the scenarios of the Galactic disk formation.

1 Introduction

The hierarchical formation scenario is a great success in describing the formation of the large-scale structure of the universe. But, the detailed mechanisms of formation of individual galaxies are still an open question. Some answers to this question rely on the knowledge of the position, the kinematics and chemical composition of the stars of the Milky Way. Therefore, in 2000, ESA has approved the Gaia mission that will provide the 6-D (position-velocity) information for 50 millions stars in the Galaxy. The expected launch of the Gaia satellite is planned for 2011. As a precursor in the spectroscopic area, an international cooperation called "RAdial Velocity Experiment" (RAVE) has started in 2003 a survey of one million stars in the southern sky hemisphere (Steinmetz, 2003). There has been already two data releases. The first release contains about 25 000 radial velocity measurements (Steinmetz *et al*, 2006) . The second data release contains about 25 000 radial velocity measurements more and 20 000 stars for which the stellar parameters ($[M/H]$, $\log g$, T_{eff}) have been determined (Zwitter *et al*, 2008). The spectroscopic acquisition techniques differ between RAVE and the Gaia Radial Velocity Spectrometer (RVS), although they have almost the same resolution and wavelength range.

---

[1] Astrophysical Institute Potsdam, An der Sternwarte 16, 14482 Postdam, Germany
[2] Observatoire Astronomique de Strasbourg, 11 rue de l'Universit, 67000 Strasbourg, France
[3] University of Ljubljana, Department of Physics, Jadranska 19, 1000 Ljubljana, Slovenia
[4] Anglo-Australian Observatory, Coonabarabran, NSW 2357, Australia
[5] Rudolf Peierls Centre for Theoretical Physics, 1 Keble Road, Oxford, UK
[6] School of Physics, University of Sydney, NSW 2006, Australia
[7] Research School of Astronomy & Astrophysics, Mount Stromlo Observatory, Cotter Road, Weston ACT 2611, Australia
[8] Centre for Astrophysics, University of Central Lancashire, Preston, UK
[9] Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge, UK
[10] Astronomisches Rechen-Institut, Zentrum für Astronomie der Universität Heidelberg, Mönchhofstrae 12-14, 69120 Heidelberg, Germany
[11] Kapteyn Astronomical Institute, University of Groningen, P.O. Box 800, 9700 AV Groningen, Netherlands
[12] Osservatorio Astronomico di Padova - INAF, Sede di Asiago, 36012 Asiago, Italy
[13] Department of Physics and Astronomy, University of Victoria, P.O.Box 3055, Victoria, Canada
[14] Department of Physics, Macquarie University, NSW 2109, Australia
[15] Planetary & Space Sciences Research Institute, The Open University, Milton Keynes, UK
[16] Department of Physics and Astronomy, Johns Hopkins University, 3400 N. Charles Street, Baltimore, USA

The RAVE spectra are obtained with the multi-fiber spectrograph 6dF (Watson *et al*, 2000) on the UK Schmidt telescope at the Anglo-Australian Observatory. Each field is observed during five exposures of 600 seconds. The RVS is an integral field instrument on board of the Gaia satellite that will not use fibers (Katz *et al*, 2004). The observation will be done in a time delay integration scan mode. Each spectrum will be exposed for 4 seconds.

The 6dF spectrograph and RVS are medium resolution instruments with $R = 7500$ and 11500, respectively. The spectra have a near infrared wavelength range between [8470 - 8740] Å for Gaia-RVS and [8410 - 8795] Å for RAVE. This wavelength range and resolution have three main advantages (Munari, 1999, 2003). They present the lowest possible contamination by telluric absorptions that will facilitate the pre- and post- Gaia mission observations from the ground. According to the Galaxy model, the largest number of stars that will be observed by Gaia will have an energy distribution that peaks in this wavelength range due to their spectral type or the interstellar extinction. In this wavelength range, the presence of the CaII triplet lines for cool stars, the Paschen lines for hot stars and metallic lines will be useful to determine accurately radial velocity and chemical abundances.

2 A model of Galactic kinematics

In order to analyze the spectroscopic data in combination with the photometric information and proper motion, we have developed a self-consistant model of the Galactic disk. The disk is describe as sum of 20 isothermal stellar components with a vertical velocity dispersion σ_{zz} ranging from 10 to 70 km.s^{-1}. The distribution function of each component is built from three elementary functions describing the vertical density ρ_i, the kinematic distribution f_i (3D-gaussians) and the luminosity function ϕ_{ik}.

We define $\mathcal{N}(z, V_R, V_\phi, V_z; M)$ to be the density of stars in the Galactic position-velocity-absolute magnitude space:

$$\mathcal{N} = \sum_{ik} \rho_i(z) f_i(V_R, V_\phi, V_z) \phi_{ik}(M), \tag{2.1}$$

where the index i differentiates the stellar components and the index k the absolute magnitudes used to model the luminosity function.

We insert this model in the generalized equation of stellar statistics giving:

$$A(m, \mu_l, \mu_b, V_r) = \int N(z, V_R, V_\phi, V_z; M)\, z^2\, \omega\, dz. \tag{2.2}$$

To determine $A(m)$, the apparent magnitude count, together with the marginal distributions of the proper motion μ_l and μ_b and the distributions of radial velocities for any direction and apparent magnitudes.

Assuming the stationarity of the density distribution, the consistency between the vertical velocity $\sigma_{zz,i}$ and density $\rho_i(z)$ distributions for each stellar component i is ensured by the following expression:

$$\rho_i(z) = \exp\left(-\Phi(z)/\sigma^2_{zz,i}\right) \tag{2.3}$$

where $\Phi(z)$ is the vertical gravitational potential at the solar Galactic position.

For the vertical gravitational potential, we use the recent determination obtained by Bienaymé et al. 2006. The vertical potential is defined at the solar position by:

$$\Phi(z) = 4\pi G \left(\Sigma_0 \left(\sqrt{z^2 + D^2} - D\right) + \rho_{\rm eff}\, z^2\right)$$

with $\Sigma_0 = 48\,\mathrm{M}_\odot\,\mathrm{pc}^{-2}$, $D = 800\,\mathrm{pc}$ and $\rho_{\rm eff} = 0.07\,\mathrm{M}_\odot\,\mathrm{pc}^{-3}$.

The kinematical model is given by shifted 3D gaussian velocity ellipsoids. For simplicity, we assume that the $\sigma_{RR}/\sigma_{\phi\phi}$ ratio is the same for all the stellar components. The velocity ellipsoids are inclined along the Galactic meridian plane. The main axis of velocity ellipsoids are set parallel to confocal hyperboloids as in Stäckel potentials. The focus is set to z_{hyp}=6 kpc on the main axis giving them realistic orientations (see Bienaymé, 1999).

The luminosity function of each stellar component is modeled with n different kinds of stars according to their absolute magnitude:

$$\phi_i(M) = \sum_{k=1,n} \phi_{ik}(M) = \frac{1}{\sqrt{2\pi}\sigma_M} \sum_{k=1,n} c_{ik}\, e^{-\frac{1}{2}\left(\frac{M-M_k}{\sigma_M}\right)^2}$$

where c_{ik} is the density for each type of star (index k) of each stellar component (index i).

3 Results

We have have adjusted the density of each stellar component to a sample of stars extracted from the 2MASS catalogue for the photometric data, the UCAC2 catalogue for proper motion and RAVE for the radial velocity. These stars are selected in color with J-K = [0.5-0.7]. In this color interval, we have defined 4 types of stars: Stars with a mean absolute magnitude $M_{\rm K} = -1.61$ are identified to be the red clump giants ($k = 1$), with $M_{\rm K} = -0.89$ and $M_{\rm K} = -0.17$ are first ascent giants stars ($k = 2 - 3$) and with $M_{\rm K} = 4.15$ for dwarfs ($k = 4$). We neglected sub-giant populations with an absolute magnitude $M_{\rm K}$ between 0.2 and 2. We adopt $\sigma_M = 0.25$ for each kind of stars on the luminosity function.

Adjusting the Galactic kinematical model to star counts, proper motions and radial velocities histograms, we obtained a kinematical decomposition of the Galactic disk (Fig. 1 left). The kinematical decomposition exhibits three main structures. We propose to identify the first one with vertical velocity dispersion $\sigma_W =$ [10-25] $\rm km\,s^{-1}$ with the thin disk, the second with $\sigma_W =$ [30-45] $\rm km\,s^{-1}$ with the thick disk. The decomposition shows a clear separation between the thin and thick components. For the third component with $\sigma_W =$ [60-70] $\rm km\,s^{-1}$, the kinematical information is missing. This component could be a 'hot' kinematically thick disk or the halo.

From the kinematical decomposition, the scale height of the thin and thick disk could be determined independently by fitting an exponential on the density $\rho(z)$ (Fig. 1 right). We find a scale height for stellar components with $\sigma_W =$ [10-25] $\rm km\,s^{-1}$ (thin disk) of 225±10 pc, for stellar components with $\sigma_W =$ [30-45] $\rm km\,s^{-1}$ (thick disk) of 1048±36 pc and the density ratio of thick to thin disk stars to be 8.7% at z=0 pc. Our values are in agreement with previous determinations like the ones of Cabrera-Lavers *et al* (2005) who have obtained a scale height of 267±13 pc and 1062±52 pc for the thin and thick disks respectively.

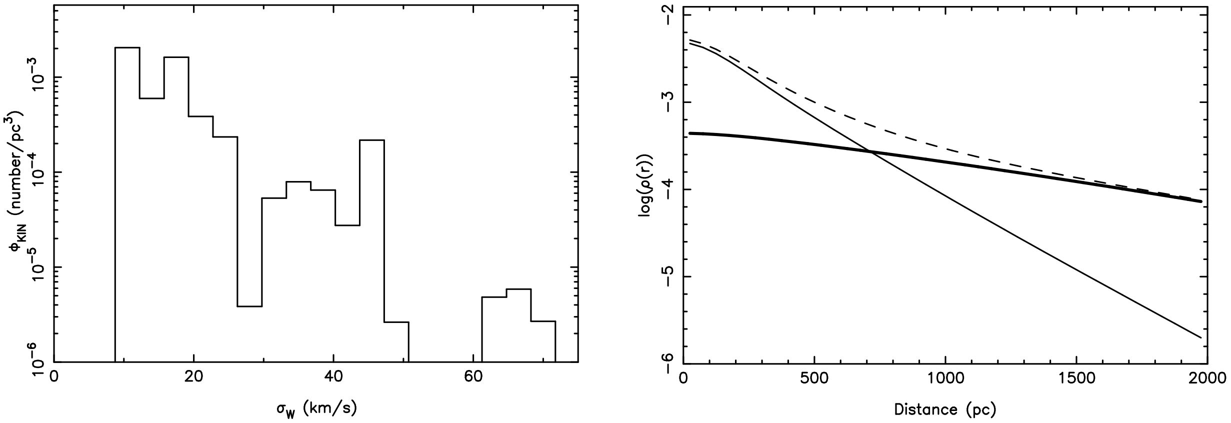

Fig. 1. On the left: Kinematical decomposition of the Galactic disk. On the right: The logarithm of the vertical stellar density $\rho(z)$ towards the the North Galactic Pole (dashed line) and its thin and thick disk decomposition (respectively thin and thick lines).

From our model, the solar motion relative to the LSR and the asymmetric drift were also determined. We obtained a value of $u_\odot$=8.5±0.3 $\rm km\,s^{-1}$, $w_\odot$=11.1±1.0 $\rm km\,s^{-1}$ and a thick disk lag is $V_{\rm lag} = 33\pm2\,\rm km\,s^{-1}$ relative to the LSR. $v_\odot$ was fixed to $= 5.2\,\rm km\,s^{-1}$, otherwise we could not measure the asymmetric drift.

By looking at latitude $|b| > 20°$, we measure a radial scale length of 2.5±0.4 kpc for the thin disk and 3.5±1.0 kpc for the thick disk. There is no consensus on the values of the scale length of the values of the scale length of the thin and thick disk, but our values are in relative agreement, for example, with Ojha (2001) who finds 2.8±0.3 kpc for the thin disk and $3.7^{0.8}_{-0.5}$ kpc for the thick disk.

4 Conclusions

The fact that the decomposition of the Galactic disk reveals the kinematical separation of the thin and the thick disk puts some constraints on the scenarios of the Galactic disk formation. The thick disk could not have been created by a continuous 'heating' mechanism like the diffusion due to molecular clouds or spiral arms.

The scientific use of the RAVE data has already permitted us to obtain a lot of results on Galactic structure and kinematics: constrains on the local Galactic escape speed (Smith *et al*, 2007), absence of the Sgr stream near the Sun (Seabroke *et al*, 2008), scale height of the thin and thick disk (Veltz *et al*, 2008), vertical tilt of the ellipsoid (Siebert *et al*, 2008). With the accuracy and number of stars that will be observed by Gaia, the future is very promising for the analysis of the structure and kinematics of the disk. All these new informations will help to improve our understanding of the formation and evolution not only of the Milky Way but also the galaxies in general.

Acknowledgments

Funding for RAVE has been provided by the Anglo-Australian Observatory, by the Astrophysical Institute Potsdam, by the Australian Research Council, by the German Research Foundation, by the National Institute for Astrophysics at Padova, by The Johns Hopkins University, by the Netherlands Research School for Astronomy, by the Natural Sciences and Engineering Research Council of Canada, by the Slovenian Research Agency, by the Swiss National Science Foundation, by the National Science Foundation of the USA, by the Netherlands Organisation for Scientific Research, by the Particle Physics and Astronomy Research Council of the UK, by Opticon, by Strasbourg Observatory, and by the Universities of Basel, Cambridge, and Groningen.
The RAVE web site is at http://www.rave-survey.org.

References

Bienaymé, O., 1999, A&A, 341,86

Bienaymé, O., Soubiran, C., Mishenina, T. V., Kovtyukh, V. V. & Siebert, A., 2006, A&A, 446, 933

Cabrera-Lavers, A., Garzn, F., Hammersley, P. L., 2005, A&A, 433, 173

Katz, D., Munari, U., Cropper, M., Zwitter, T., Thvenin, F. *et al*, 2004, MNRAS, 354, 1223

Munari, U., 1999, Baltic Astronomy, 8, 73

Munari, U., 2003, editor, ASPC: "GAIA Spectroscopy: Science and Technology", 298

Ojha, D. K., 2001, MNRAS, 322, 426

Seabroke, G. M., Gilmore, G., Siebert, A., Bienaymé, O., Binney, J. *et al*, 2008, MNRAS, 384, 11

Siebert, A., Bienaymé, O., Binney, J., Bland-Hawthorn, J., Campbell, R. *et al*, 2008, arXiv0809.0615

Smith, M. C., Ruchti, G. R., Helmi, A., Wyse, R. F. G., Fulbright, J. P. *et al*, 2007, MNRAS, 379, 755

Steinmetz, M., 2003, ASPC: "Gaia Spectroscopy: Science and Technology", 298, 381

Steinmetz, M., Zwitter, T., Siebert, A., Watson, F. G., Freeman, K. C. *et al*, 2006, AJ, 132, 1645

Veltz, L., Bienaymé, O.; Freeman, K. C., Binney, J., Bland-Hawthorn, J. *et al*, 2008, A&A, 480, 753

Watson, F. G., Parker, Q. A., Bogatu, G., Farrell, T. J., Hingley, B. E., & Miziarski, S., 2000, Proc. SPIE, 4008, 123

Zwitter, T., Siebert, A., Munari, U., Freeman, K. C., Siviero, A. *et al*, 2008, AJ, 136, 421