SF2A 2010
S. Boissier, M. Heydari-Malayeri, R. Samadi and D. Valls-Gabaud (eds)

THE BESANÇON GALAXY MODEL: COMPARISONS TO PHOTOMETRIC SURVEYS AND MODELLING OF THE GALACTIC BULGE AND DISC

C. Reylé[1], A. C. Robin[1], M. Schultheis[1] and D.J. Marshall[2]

Abstract. Exploring the in-plane region of our Galaxy is an interesting but challenging quest, because of the complex structure and the highly variable extinction. We here analyse photometric near-infrared data using the Besançon Galaxy Model in order to investigate the shape of the disc and bulge. We present new constraints on the stellar disc, which is shown to be asymmetric, and on the bulge, which is found to contain two populations. We present how the Galaxy model is used in the framework of the preparation of the Gaia mission.

Keywords: stellar population model, bulge, disc, large scale survey, Gaia

1 Introduction

The population synthesis approach aims at assembling together current scenarii of galaxy formation and evolution, theory of stellar formation and evolution, models of stellar atmospheres and dynamical constraints, in order to make a consistent picture explaining currently available observations of different types (photometry, astrometry, spectroscopy) at different wavelengths. The validity of any Galactic model is always questionable, as it describes a smooth Galaxy, while inhomogeneities exist, either in the disc or the halo. The issue is not to make a perfect model that reproduces the known Galaxy at any scale. Rather one aims at producing a useful tool to compute the probable stellar content of large data sets and therefore to test the usefulness of such data to answer a given question in relation with Galactic structure and evolution. Modelling is also an effective way to test alternative scenarii of galaxy formation and evolution.

In section 2, we give a brief description of the model. In section 3 we describe recent and future analysis of near-infrared data with the model. In section 4 we describe the use of the model for the preparation of the Gaia mission.

2 The Besançon Galaxy model: ingredients and recipe

The main scheme of the model is to reproduce the stellar content of the Galaxy, using some physical assumptions and a scenario of formation and evolution. We essentially assume that stars belong to four main populations : the thin disc, the thick disc, the stellar halo, and the outer bulge. The modelling of each population is based on a set of evolutionary tracks, assumptions on density distributions, constrained either by dynamical considerations or by empirical data, and guided by a scenario of stellar formation and evolution, that is to say assumptions on the initial mass function (IMF) and the star formation rate (SFR) history for each population. The originality of the Besançon model, as compared to a few other population synthesis models presently available for the Galaxy, is the dynamical self-consistency. The Boltzmann equation allows the scale height of an isothermal and relaxed population to be constrained by its velocity dispersion and the Galactic potential (Bienaymé et al.1987). The use of this dynamical constraint avoids a set of free parameters and gives the model an improved physical credibility. More detailed descriptions on these constraints can be found in Robin et al. 2003. Simulations can be performed on-line.*

[1] Observatoire de Besançon, Institut Utinam, UMR CNRS 6213, BP 1615, 25010 Besançon Cedex, France
[2] Centre d'Etude Spatiale des Rayonnements, UMR 5187, 9, av du Colonel Roche, BP 44346, 31028 Toulouse Cedex 4, France
*`http://model.obs-besancon.fr`

Observational tests have been made in many directions in the optical, mostly at high latitudes, a few directions to magnitudes V=24-25 (Robin et al. 2000, Reylé & Robin 2001, Schultheis et al. 2006, Robin et al. 2008). An all-sky comparison has been made with the Guide Star Catalogue 2 (GSC2, see Fig. 1). The model has also been constrained using near-infrared data (Picaud & Robin, Reylé et al. 2009), X-ray data (Guillout et al. 1996), and UV (Todmal et al. 2010).

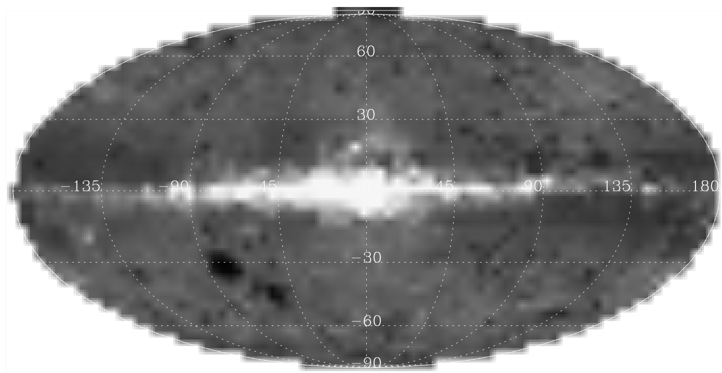

Fig. 1. Relative difference map, (model - GSC2)/GSC2, on a log scale, to magnitude V=17. The agreement is at 10% outside plane. Most of the discrepancy between the model and the observations are within of the Galactic plane, probably due to inadequate extinction in the plane (Drimmel et al. 2003).

3 Constraints on the external disc and central regions

The 2MASS survey is a powerful tool to study large scale structure in the Galaxy, particularly in the Galactic plane because NIR data are well suitable to study stellar populations in regions of medium to high extinction. A good estimate of the extinction is required to understand the structure in the Galactic plane. In the following studies, we used a three dimensional extinction map of the Galaxy (Marshall et al. 2006).

From the comparison of 2MASS star counts with the Besançon Galaxy model, we investigated the warp feature followed by stars (Reylé et al. 2009). We modelled the warp as a simple S-shape symmetrical but found that the warp is not symmetrical: the simple model reproduces well the northern side of the warp (positive longitudes), but not the southern side. The results also show that the stellar warp is less marked in stars than in the HI gas. Our result is well in agreement with studies in external galaxies, where van der Kruit (2007) noted that stellar discs look flatter than gas layers. This is understandable in a scheme where the HI warps start close to the truncation radius, truncation seen in the exponential distribution of stars which may be due to a threshold effect in the star formation efficiency.

Since the discovery of a triaxial structure in the Galactic central regions from COBE, numerous attempts have been done in order to characterize this structure and to investigate its origin. It is still unclear whether this structure had its origin from the early formation of the spheroid (as a typical bulge, similar to ellipsoidal galaxies) or was formed by a bar instability later in the disc. The question of formation history is crucial and necessary to investigate, as our Galaxy is a benchmark for understanding formation of disc galaxies. Thanks to the ability of the model to simulate the stellar populations as they are seen in surveys, we compared model simulations with 2MASS star counts in all the region covered by the outer bulge. We show evidence for two independent structures, a triaxial bulge and a long and narrow structure which angles are different (Fig. 2, Robin et al., in prep.). Further studies are needed to confirm these preliminary conclusions, in particular kinematical data, helpful in understanding the dynamics, especially to measure the rotation and velocity dispersions of these populations.

4 The Besançon Galaxy model for the preparation of the Gaia mission

Preparing the Gaia mission requires large efforts dedicated to simulations of the observations. Several simulators have been constructed, generating telemetry, images, or the final database. All these tools use a Universe Model containing essentially the astronomical sources to be seen by Gaia and their characteristics, as well as a Relativity model and a radiation model for estimating the potential damage to the CCDs. The stellar content

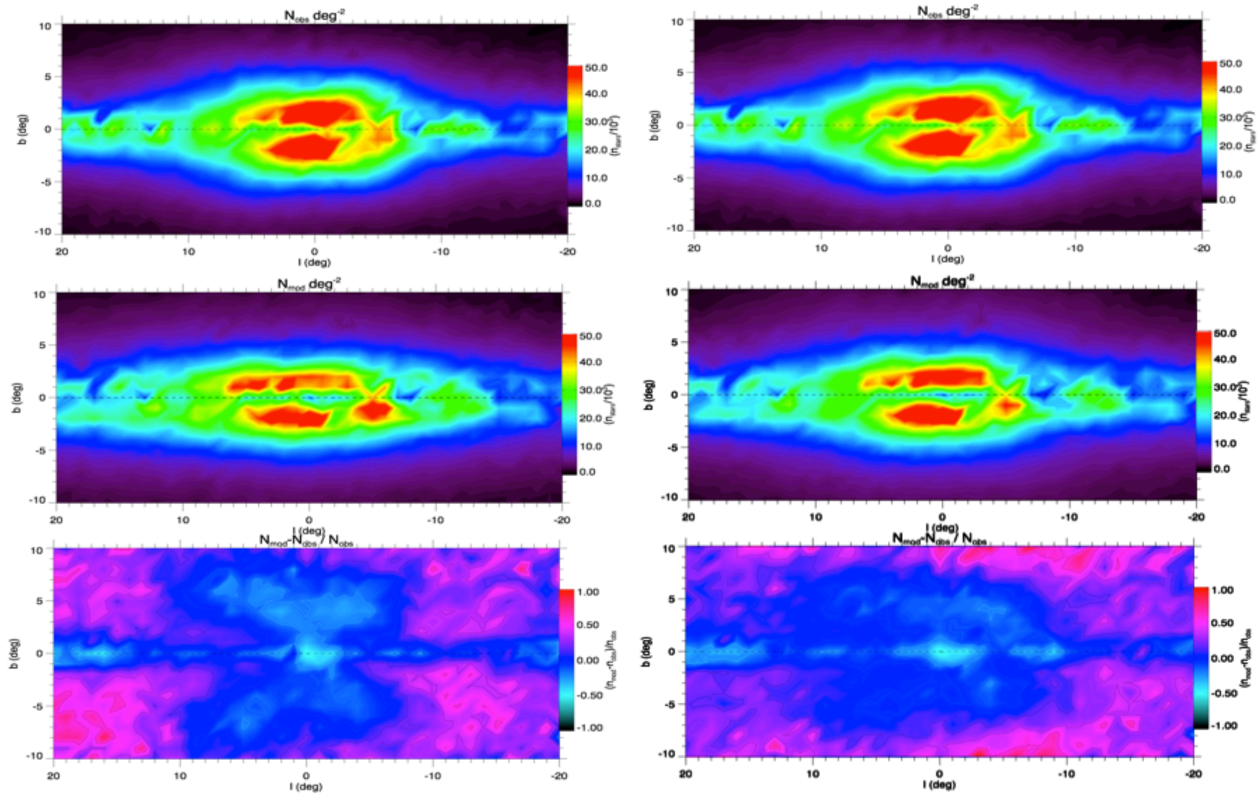

Fig. 2. Star counts up to magnitude K=12 from 2MASS data (top) compared with 2 models (middle panels) and residuals (Nmod-Nobs)/Nobs (bottom). Left: model with 1 bulge population. Right: model with 2 populations : a triaxial bulge and a thin elongated structure. In pink the excess in the model is at the level of 70%. The light blue corresponds to a lack in the model at the level of 50%. The 2-population model allows to nicely reproduce the boxy shape of the outer bulge region, while the 1-population model leaves significant X-shaped residuals. Near the Galactic center the nuclear bar population is missing in the model. The residuals in the outer region are not much significant due to the small number of stars in each bin.

of the Universe Model is simulated using the Besançon Galaxy model (Isasi et al. 2010). Fig. 3 shows the expected density of stars to magnitude G=20 as a function of galactic coordinates. The expected total number of stars is $1.3{\times}10^9$ ($8.7{\times}10^8$ disc stars, $2.6{\times}10^8$ thick disc stars, $15{\times}10^6$ halo stars, and 10^8 bulge stars). Fig. 4 gives the expected number of stars as a function of spectral type and luminosity class. The right panel in Fig. 3 shows the expected density of stars in the (X,Y) plane, centered on the Sun. The sharp radius towards the anticenter is due to the cut-off radius of the thin disc at 14 kpc (from Ruphy et al. 1996). The Gaia data will bring a strong constraint on the shape and radius of the disc, as well as on many other parameters.

5 Conclusions

Population synthesis models are useful tools for data interpretation. Although imperfect they allow a better understanding of galactic structure and evolution, eases the interpretation, and is useful for the preparation of future surveys. Gaia will obtain distance, proper motions of more than 1 billion stars (about 1% of the Galaxy) as well as astrophysical parameters, radial velocities for about 250 million stars, and abundances for a few million stars. It will be a challenge to fit Gaia data with (simplistic) models! Since then, efforts have to been made to get stellar population models with self-consistent dynamical modelling.

References

Bienaymé, O., Robin, A. C., Crézé, M. 1987, A&A, 180, 94

Drimmel, R., Cabrera-Lavers, A., López-Corredoira, M. 2003, A&A, 409, 205

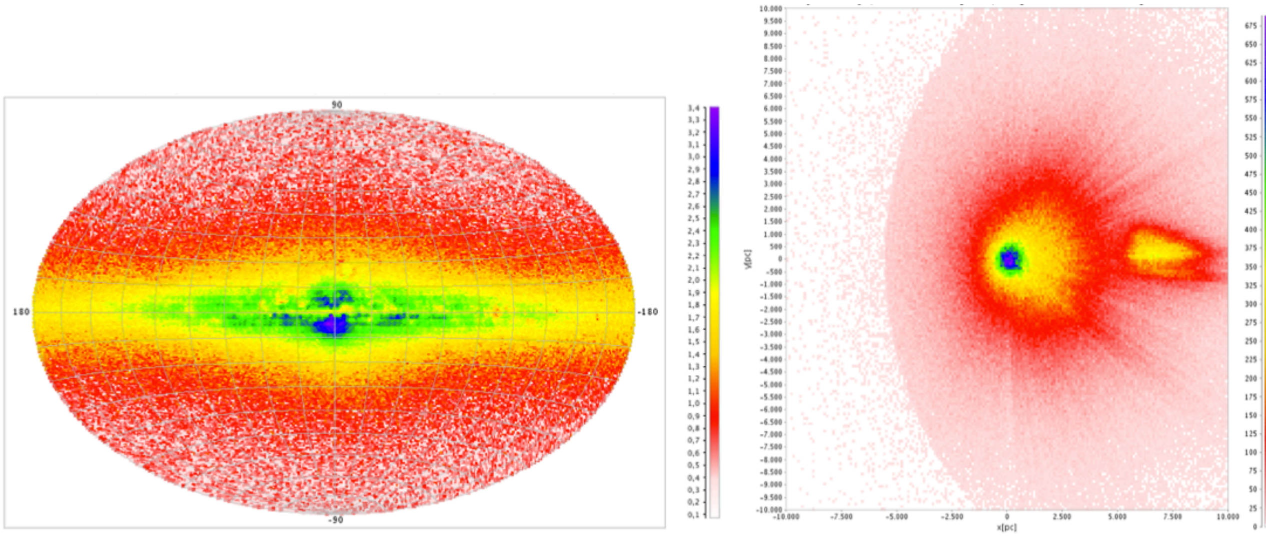

Fig. 3. Left: Expected total sky density (log of the number of objects per square degree) to magnitude G=20 from the Gaia Universe Model simulations (GUMS). Right: Expected total sky density in the X,Y plane, centered on the Sun.

spectralType	Total
O	3
B	3589
A	24916
F	296763
G	473337
K	349763
M	99937
L	1
Be	0
WR	0
AGB	9817
Other	1183
Total	1259309

lumClass	Total
BrightGiant	8812
Giant	173305
MainSequence	885651
Other	401
PreMainSequence	4584
SubGiant	185774
SuperGiant	18
WhiteDwarf	764
Total	1259309

Fig. 4. Expected number of stars $\times 10^{-3}$ at magnitude G=20 from the Gaia Universe Model simulations (GUMS).

Guillout, P., Haywood, M., Motch, C., Robin, A. C. 1996, A&A, 316, 89

Isasi, Y., Figueras, F., Luri, X., Robin, A. C. 2010, Highlights of Spanish Astrophysics V, 415

Marshall, D. J., Robin, A. C., Reylé, C., Schultheis, M., Picaud, S. 2006, A&A, 453, 635

Picaud, S., & Robin, A. C. 2004, A&A, 428, 891 bibitemReylé, C., Robin, A. C. 2001, A&A, 373, 886

Reylé, C., Marshall, D.J., Robin A.C., Schultheis, M. 2009, A&A 495, 819

Robin, A. C., Reylé, C., Crézé, M. 2000, A&A, 359, 103

Robin, A. C., Reylé, C., Derrière, S., Picaud, S. 2003. A&A, 409, 523 -540

Robin, A. C., Rich, R. M., Aussel, H. et al. 2007, ApJS, 172, 545

Ruphy, S., Robin, A.C., Epchtein, N., Copet, E., Bertin, E., Fouqué, P., Guglielmo, F. 1996, A&A, 313, L21

Schultheis, M., Robin, A. C., Reylé, C., McCracken, H. J., Bertin, E., Mellier, Y., Le Fèvre, O. 2006, A&A, 447, 185

Todmal, S.S, Gosh, S.K., Ojha, D.K., Robin, A.C. 2010, Bull. Astr. Soc. India, 1, 205

van der Kruit, P.C., 2008, in Formation and Evolution of Galaxy Disks, ASP Conference Series, Eds. J. G. Funes, S.J., E. M. Corsini