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SIMULATING THE GALAXY AND APPLICATIONS TO THE PREPARATION OF THE GAIA MISSION

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Abstract. The preparation of the Gaia mission requires simulations of the stellar content of the Galaxy with detailed estimates of the intrinsec properties of the stars, as well as the overall structure of the Galaxy. We present a few distribution in luminosity class and spectral type of the stars visible by Gaia instruments and a new development of the model concerning the populations in the Galactic bulge.

Keywords: Galaxy:stellar content, Galaxy:evolution, Galaxy:structure

1 Introduction

The Gaia mission will give a detailed view, with unprecedented accuracy, of the stellar content of the Galaxy. It will encompass any model that we can make at the time being. However models are still useful to prepare the mission, for providing simulations of the intermediate and final catalogues of the mission, to test algorithms in good conditions before launch, and to provide testbeds for the data analysis methods. In order to achieve Gaia simulations, a coordination unit (CU2) has been established inside the Gaia Data Processing and Analysis Consortium (Gaia-DPAC) in order to provide to other members of the consortium the necessary simulations. CU2 has to implement the simulators which are three at this time : GIBIS, generating images, GASS, generating telemetry data, and GOG for intermediate and final catalogues simulations. All three simulators use two models to simulate the data : the Universe Model and the Instrument Model. One important aspect of the Universe Model concern the stellar content of the Milky Way, which will provide more than 90% of the sources in the Gaia instrument.

CU2 has chosen to base its Galaxy model on the Besançon Galaxy Model (Robin et al. 2003). However the DPAC needed more detailed simulations than in this standard model and improvements have been introduced in the scheme, like the simulation of binary and multiple stars, intrinsec and extrinsec (microlensing) stellar variabilities, simulations of extended objects (HII regions, planetary nebulae) and varying backgrounds (zodiacal light), as well as stars with exoplanets. An overall description of the Universe model can be found in Robin et al. (2011a).

The Gaia simulators have been used to estimate the number of stars of different kinds which are expected in the Gaia telescopes. Examples of these numbers are given here. These numbers are still subject to change before launch because our knowledge evolves and we shall attempt to introduce as much as reality as possible in the simulations in order that people trying to exploit the data can rely on it. The typical usages of these simulations are to test the sofwares, in particular the classification schemes, that can be very sensitive to the frequency of the type of objects to classify.

In this paper we summarize the typical star count expectations in the Gaia instruments. In Sect. 2 we present the way the Galaxy stellar content is simulated for the Gaia preparation. In Sect. 3, we show estimations of the numbers and properties of stars that Gaia will see. And in Section 4 we show on-going work for improving the modelling of the Galaxy in the bulge region.

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Table 1. Number of stars of each luminosity class over 1/8th of the sky up to limiting magnitude $G \leq 20$ and $G_{\rm RVS} \leq 12$. Level 0 concerns single stars only. Level 1 is for objects in star systems with at least two components.

	$G \leq 20$			$G_{RVS} \leq 12$		
Luminosity class	Level 0	Level 1	Total	Level 0	Level 1	Total
Supergiants	14	32	46	14	32	46
Bright giants	15653	54492	70145	6595	21443	28038
Giants	1832214	3236786	5069000	220641	538672	759313
Subgiants	3253211	4526679	7779890	60142	114217	174359
Main Sequence	33223926	33752099	66976025	118576	189104	307680
PreMain sequence	41616	42429	84045	3067	5619	8686
White dwarfs	29140	59881	89021	7	3832	3839
Total	38395774	41672398	80068172	409042	872919	1281961

2 Modelling what Gaia will see

The Universe Model developed for the simulation of the mission is a set of algorithms for computing the positions at any time and observational properties of any objects expected to be observed by the Gaia instruments.

The distributions of these objects and the statistics of observables should be as realistic as possible for simulations to be usable for estimating telemetry, testing software, simulating images, etc. The algorithms have to be optimised in order that the simulations can be performed in reasonable time and can be redone when necessary. The complexity of the model increases with time during the preparation of the mission. The numbers presented here have been obtained from the cycle 10 version of the simulator (2011).

Simulated objects are: solar system objects (planets, satellites, asteroids, comets), Galactic objects (stars, nebulae, stellar clusters, diffuse light), extragalactic objects (galaxies resolved in stars, unresolved but extended galaxies, quasars and active galactic nuclei, supernovae). For each of these simulated objects one needs to have their full 3D spatial distribution together with their spectral characteristics (to be able to compute photometry and spectroscopy, stable or variable in time), and their motions (for astrometric computations and for spectral corrections).

In order to simulate the sky content, the sky is subdivided in small regions with a Hierarchical Triangular Mesh (HTM, see `http://skyserver.org/htm/`). The Universe Model presently uses the 3D extinction model from Drimmel & Spergel (2011). A complete description of the Universe Model used for Gaia simulations can be found in Robin et al. (2011a).

3 Estimations of the stellar content in the Gaia mission

From the Universe Model and from the generators of the final catalog (GOG) it is possible to evaluate the number of each kind of astronomical sources that Gaia will see. We here give a few numbers from a simulation of 1/8th of the sky with version 10 of the simulator. It concerns only stars in the Galaxy, excluding stars in neighbourhood galaxies and other astronomical sources. More up to date numbers for the whole sky will be presented in a forth coming paper (Robin et al., in prep). Table 1 gives the number of stars of each luminosity class and Table 2 the distribution in spectral type. The numbers are given for each hierarchy level. Level 0 concerns single stars only. Level 1 is for objects in star system with at least two components. Numbers are given for two limiting magnitude. At $G < 20$, the stars will have photometry and astrometry measured. At $G_{RVS} \leq 12$, stars will have very accurate radial velocity and abundance measurements from the spectrograph RVS. At the limiting magnitude of the RVS (between 16 and 17 depending on the spectral type) stars will have a rough estimate of the radial velocity and a metallicity index but no elemental abundances.

4 Recent model improvements : the bulge/bar population

Continuing our efforts to improve the realism of the model, and to find constraints on the formation scenario for each of the galactic components, we have turned our eyes towards the bulbe/bar region to find out whether it is possible to deduce such constraints from large surveys. The first step is to establish the distribution of the light in 3D from analysis of 2MASS near infrared star counts. The mass distribution will be straighforwardly

Table 2. Number of stars of each spectral type over 1/8th of the sky up to limiting magnitude G=20, to G_{RVS} =17, and G_{RVS}=12. Level 0 concerns single stars only. Level 1 is for objects in star system with at least two components. L dwarf counts are included only up to L5.

	$G \leq 20$			$G_{RVS} \leq 17$			$G_{RVS} \leq 12$		
Sp. Type	Level 0	Level 1	Total	Level 0	Level 1	Total	Level 0	Level 1	Total
O	0	5	5	0	5	5	0	5	5
B	22957	88754	111711	16358	77367	93725	2681	15250	17931
A	424842	1186894	1611736	331214	963217	1294431	20679	66433	87112
F	7490020	9580207	17070227	3415861	5038394	8454255	80922	159564	240486
G	12864111	14079527	26943638	5153553	6186141	11339694	91053	170381	261434
K	12086280	12183767	24270047	4179879	4964899	9144778	176810	408939	585749
M	5477126	4480471	9957597	1549717	1324498	2874215	36211	45288	81499
L	12	12	24	4	7	11	0	0	0
AGB	516	361	877	503	346	849	426	271	697
Other	29910	72400	102310	1682	21028	22710	260	6788	7048
Total	38395774	41672398	80068172	14648771	18575902	33224673	409042	872919	1281961

deduced from it. Further, metallicities and kinematics can be attached to each population to understand the chemo-dynamical histoty of its formation. For doing so, we extended the approach made by Picaud & Robin (2004) to a wider area of the bulge (–20°$< l <$ 20° and –10°$< b <$10°). A Monte-Carlo scheme is used to explore the multidimensional space of model parameters. These model parameters are the density function of the bulge population (a triaxial Ferrer ellipsoid defined by 3 scale lengths, 3 orientation angles, 2 parameters for the boxyness, a normalisation factor, and a cutoff radius), plus 2 parameters for the thin disc, which is a really important population in the plane towards the bulbe. The thin disc is parametrized by a Einasto (1979) density law, with a scale length, and a scale length for the inner hole, as in Robin et al. (2003). The following equations give the shapes of the fitted bulge population which have been tested : $\rho_S = \rho_0\ \mathrm{sech}^2(-R_s)$ or $\rho_E = \rho_0\ \exp(-R_s)$ or $\rho_G = \rho_0\ \exp(-R_s)^2$ with

$$R_s^{C_\parallel} = \left[\left|\frac{X}{x_0}\right|^{C_\perp} + \left|\frac{Y}{y_0}\right|^{C_\perp} \right]^{C_\parallel/C_\perp} + \left|\frac{Z}{z_0}\right|^{C_\parallel} \tag{4.1}$$

where (X,Y, Z) are the cartesian coordinates in the referential of the triaxial structure (X being the major axis, Y the second axis and the Z the third). The parameters $C_\parallel$ and $C_\perp$ are important to explore a wide range of shapes, from disky to boxy. This allows a great flexibility : one can even have a disky shape in the plane, together with a boxy projection vertically.

The counts are simulated assuming a bulge population of age 8 Ga from Padova isochrones Girardi et al (2002) for different metallicities. The age is not a very sensitive parameters in star counts from broad band photometry. For the simulation we use the Marshall et al (2006) 3D extinction model. The simulated counts are compared with observed counts in bins in the space $(K, J-K)$ and a likelihood is computed. While attempting to fit a unique bulge population with a single shape, we realized that the resulting fit was not satisfactory in all the studied region. We then attempted to fit the population with the sum of two ellipsoids and find out a much better global fit over the whole bulge region. The counts and residuals from the data, and from the simulated counts for the 1-ellipsoid model and from the best fit model are given in Figure 1. We clearly see that the best 1-ellipsoid fit does not reproduce enough the boxiness of the bulge region, while the 2-ellipsoid model does.

5 Conclusions and further developments

The Gaia simulator using a Universe Model is able to predict the counts and the properties of the objects that Gaia will see during its mission. The total number will be about 1 billion of stars. This number depends on assumptions in the model, particularly on the assumed binary fraction and on the 3D extinction map. More detailed predictions will be provided in a forthcoming paper (Robin et al., in prep).

In parallel to providing simulations from the standard Galactic model, we attempt to improve the model and particularly towards the bulge region. We presented a new model which reproduces the 2MASS star counts in the region –20°$< l <$ 20° and –10°$< b <$10°. This model is made of the sum of two Ferrer's ellipsoids, the first

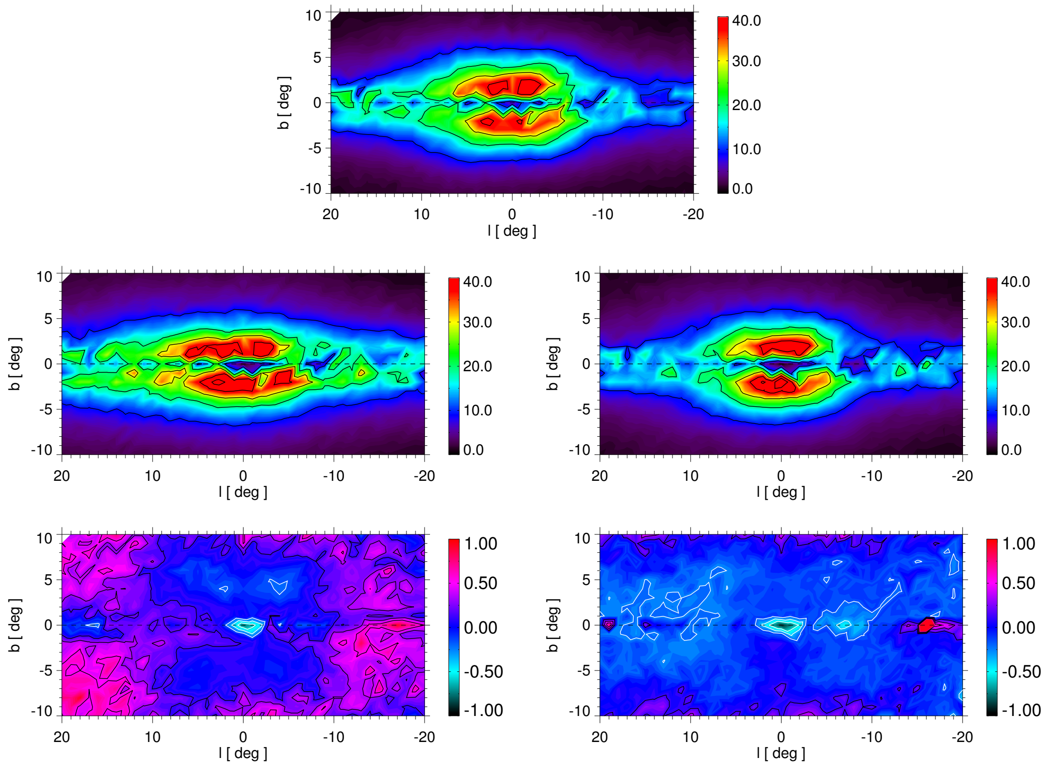

Fig. 1. Star counts up to limiting magnitude K_S from 2MASS data (top) compared with fitted 1 ellipsoid model (middle left), residuals (N_{mod}-N_{obs})/ N_{obs} (bottom left), 2-ellipsoids model (middle right) and its residuals (bottom right). In the residual map, contours are drawn at intervals of 20% model overestimate (black) and 20% model underestimate (white). Near the Galactic centre the nuclear bar population is missing in the model and thus appears in the residuals.

ellipsoid having a major axis pointing with an angle of about 13° with the sun-center axis and the scale lengths are 1.46/0.49/0.39 kpc. The second component is less massive (about 4% of the first one) and has larger scale lengths 4.44/1.31/0.80 kpc, but significantly contributes at medium latitudes. The agreement between this new models in terms of colour magnitude diagrams is very good. We also show that assuming that the first ellipsoid is inhabited by a population of solar metallicity and the second ellipsoid is a population of metallicity of -0.35 dex, we can very well reproduce the metallicity gradient which is found in Zoccali et al. (2008) along the minor axis of the bulge. From a preliminary comparison with kinematical data, we find out that the main component is the Galactic bar, and the second component can be either a classical bulge, or a population made from relics of merging, possibly related to the inner thick disc. The complete analysis and discussion can be found in Robin et al. (2011b).

References

Drimmel, R. and Spergel, D. N., 2001, ApJ 556, 181

Einasto J., 1979, IAU Symp. 84, The Large Scale Characteristics of the Galaxy, ed. W.B. Burton, p. x

Ferrers, N. M., 1877, Quart. J. Pure Appl. Math., 14, 1

Girardi, L., Bertelli, G., Bressan, A., Chiosi, C., Groenewegen, M.A.T., Marigo, P., Salasnich, B., Weiss, A. 2002, A&A, 391, 195

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

Robin, A.C., Reylé, C., Arenou, F., et al, 2011, Gaia livelink GAIA-C2-TN-LAOB-AR-004-10

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

Robin, A.C, Marshall, D.J., Schultheis, M., Reylé, C., 2011, A&A, submitted

Zoccali, M., Hill, V., Lecureur, A., Barbuy, B., Renzini, A., Minniti, D., Gómez, A., Ortolani, S. 2008, A&A, 486, 177