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INSIGHT INTO GALACTIC STRUCTURE AND EVOLUTION FROM THE POPULATION SYNTHESIS APPROACH

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Abstract. The population synthesis approach aims at understanding Galactic structure and evolution, and testing formation scenarios. Applied to the Milky Way, this approach allows the interpretation of large scale surveys and is able to place constrains on our knowledge of the Galaxy. Detailed comparisons between large scale surveys and model predictions have led to new constraints on Galactic structure and evolution of the stellar populations. Recent results concerning the Galactic warp and the study of the Galactic central region have been obtained by adjusting model parameters to the 2MASS point source catalogue. The stellar warp is found to be asymmetric and different from the HI warp. We emphasize the existence of two structures in the Galactic central region: a triaxial outer bulge coexisting with a narrow boxy bar.

1 Introduction

Stellar populations are good tracers of Galactic structure; they are numerous, nearly everywhere in the Galaxy and they furnish a number of important indices for the understanding of Galactic structure and evolution history, particularly distance indicators, age estimates and kinematical tracers. However these indices are very difficult to calibrate. The synthesis approach can be used to assert the validity of these calibrations and the consistency of the overall scheme. When scenarios of Galaxy formation and evolution are inferred from suitable constraints, tests of these scenarios can be done using population synthesis models whose predictions can be directly compared with observations. This synthetic approach ensures that biases have been correctly taken into account and that the scenario is compatible with many kinds of constraints.

In recent years wide surveys have been obtained from optical and near-infrared photometry thanks to wide mosaic camera of CCDs, from spectroscopy, and helped by the availability of dedicated telescopes and multi-object spectrometers, both from the ground and from space. All these data sets benefit Galactic evolution studies and provide constraints on the population synthesis approach. Among them, the 2MASS survey (Skrutskie et al. 2006) has provided one of these rich data sets from which substantial results have been obtained.

Here we report on two analysis of Galactic structure features which have been done applying the population synthesis approach onto the 2MASS data. In Sect. 2 we present the model and the population synthesis approach. In Sect. 3 we describe the data used and the method used to compute the extinction. In Sect. 4 we present our results concerning the external stellar disc of the Galaxy as well as its central regions. Conclusions and perspectives are given in Sect. 5.

2 The population synthesis approach

The population synthesis approach aims at assembling scenarios of galaxy formation and evolution, theories 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

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model that reproduces the known Galaxy at any scale. Rather one aims to produce 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 to Galactic structure and evolution. Modelling is also an effective way to test alternative scenarios of galaxy formation and evolution.

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 (or spheroid), 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 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).

3 2MASS survey and extinction distribution

The 2MASS survey Skrutskie et al. (2006) 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 population in regions of medium to high extinction. The first effect visible in the star density distribution close to the Galactic plane is due to the dust, even at near-infrared wavelengths. Without a good estimate of the extinction and of its distance it is nearly impossible to understand the structure in the thin disc. Hence it is essential to start by constructing a three dimensional extinction map of the Galaxy.

Extinction is so clumpy in the Galactic plane that it determines for a great part the number density of stars, more than any other large scale stellar structure. So, it is possible to extract information about the distribution of the extinction from photometry and star counts. Marshall et al. (2006) have shown that the 3D extinction distribution can be inferred from the stellar colour distributions from the 2MASS survey. Using stellar colours in J-K as extinction indicators and assuming that most of the model prediction deviations on small scales from observed colours arises from the variation of extinction along the line of sight, we built a 3D extinction map of the galactic plane ($-10 < b < 10$ and $-100 < l < 100$). The final resolution in longitude and latitude is 15 arcmin and the resolution in distance varies between 100 pc to 1 kpc, depending on stellar density and on the dust distribution along the line of sight. The resulting 3D extinction map furnishes an accurate description of the large scale structure of the disc of dust. These maps show clearly the warp in the dust distribution in the external disc. The method has now been extended to external regions (Marshall et al, in preparation).

4 Constraining Galactic structure and formation

Using this extinction map, a comparison between simulations from the Besançon Galaxy model and 2MASS star counts shows that the model reproduces the data with a high degree of realism in the plane, even without modelling the spiral arms Robin et al. (2008). It means that either the spiral structure does not have a high contrast or that 2MASS data are not a good tracer for these arms. This is expected as the model estimates that 2MASS counts are dominated by red clump giants which are rather old stars (90% have ages larger than 1 Gyr, having made at least 4 revolutions around the Galaxy) and have mainly lost the memory of their birth place (although suitable colour selections would probably place more constraints on spiral arms).

4.1 The stellar warp

Looking at 2MASS star counts in external regions, the warp is easily visible on both sides of the Galaxy. Thus we expect to be able to constrain a model of the stellar warp using this data set. In Reylé et al. (2009) we investigate the shape of the warp as seen from stellar populations. We first attempted to model the warp as a simple S-shape symmetrical warp with a slope taken from the literature Gyuk et al. (1999) (0.18), a line of node being the sun-Galactic center direction (as seen in HI). This investigation showed that the simulated warp departs too quickly from the plane (the slope value of the default model is too high). Further, it shows that the warp is not symmetrical. A simple S-shape warp reproduces well the northern side of the warp (positive longitudes) with a slope of 0.09, but not the southern side. On the southern side no simple S-shape warp reproduce the data. We also attempted to fit star counts with alternative warp models, in particular non-axisymmetric ones, like the Levine et al. (2006) model which represents in detail the HI asymmetric warp. The results how that the stellar warp is not similar to the HI warp. The agreement is not satisfactory on the southern part of the warp (negative longitudes).

The dust warp have been detected and measured by Marshall et al. (2006) in their study of the 3D extinction distribution. A comparison of the warp slope as measured in dust, HI gas and stars shows that the stellar warp slope is significantly smaller than the HI gas warp, by a factor of about 2. There is an indication that the HI gas is the strongest, the dust warp seems a bit smaller and the stellar warp is significantly smaller. However if we limit the investigation to short distances (R<12 kpc) the differences between various warp models are less important. 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).

4.2 The central region of the Galaxy : bar and/or bulge ?

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, often called the outer bulge but sometimes named the bar, 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. As in Picaud & Robin (2004) we first attempted to fit a unique old bulge population and characterized the shape of the structure which maximizes the likelihood, but in a much larger region covering $-20 < l < 20$ and $-10 < b < 10$. We investigated several shapes, using gaussian, exponential or $sech^2$ shapes, and adjusting angles, 3 axis scale lengths, 3 boxiness parameters, as well as the disc scale length and central hole. It results that the best fit bulge structure has a small angle of about 10deg with regards to the sun-Galactic center axis. However the result is unsatisfactory: this structure leaves significant residuals when we subtract the resulting simulation from the data, and the fit depends on the choice of the region fitted. In particular, when one selects regions at low latitudes and high longitudes, the fitted structure gets a higher angle, while the selection concerns regions at high latitudes and low longitudes, on the contrary the angle is found to be close to 0. It seems that we are seeing two distinct populations, the ratio of which change with longitude and latitude. Hence, we investigated this possibility and attempted to fit two populations of similar triaxial shapes. The likelihood of this two-population model is larger than the one-population model and no systematical residuals appear when looking at relative difference between model and data. We conclude that in the bulge region cohabit two different structures, a triaxial bulge with an angle of about 20deg and a narrow bar nearly aligned with the x axis. The comparison of 2MASS star counts with the 1-structure and 2-structure models is shown in figure 1. The 2-structure solution gives a very good agreement with the data, hence it appears to be a good explanation. We also explored alternative models, like a spiral arm between the sun and the Galactic center, but none gave satisfactory results.

5 Conclusions and perspectives

From the comparison of 2MASS star counts with a model of population synthesis in the outer regions of the Galaxy we investigate the warp feature followed by stars. We obtain a good fit of one side of the warp with a simple warp model but we fail to find a satisfactory fit on the other side, at negative longitudes, even with a 3 Fourier mode model like the Levine et al. (2006) gaseous warp model. Despite the uncertainties, it is clear from our study of the 2MASS star counts that the warp is less marked in stars than in the gas and it also shows different shapes at negative and positive longitudes. There is also a slight tendancy for the dust warp to be intermediate between the HI and the stars. In the central regions, we show evidence for two independent

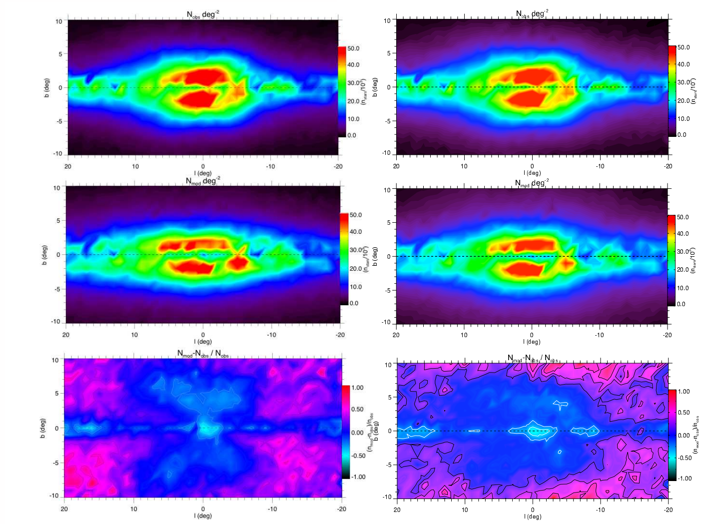

Fig. 1. Star counts up to magnitude K=12 from 2MASS data (top) compared with 2 models (middle panels) and residuals (Nmod-Nobs)/Nobs (bottom). Left pannel: model with 1 bulge population. Right: model with 2 bulge populations : a triaxial bulge and a bar. In pink the excess in the model is at the level of 70% on the left pannel. 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.

structures, a triaxial bulge and a long and narrow bar which angles are different. This long bar is different from recent studies (Hammersley et al, 2000, Benjamin et al., 2005) which have an angle of about 43-45deg. 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.

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