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Color-magnitude diagrams at low Galactic latitudes

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Abstract. Within the open cluster project BOCCE, we present a preliminary analysis of three low latitude fields imaged with the Canada-France-Hawaii telescope (CFHT), with the aim of better understanding the Galactic structure in those directions. Thanks to the deep and accurate photometry, these wide fields represent a unique and severe benchmark for galactic models. In the present paper we discuss if a canonical star count model, expressed in terms of thin and thick disk radial scales, thick disk normalization and reddening distribution, can explain the observed CMDs. The goodness of fit is evaluated with a Kolmogorov-Smirnov test. The classical decomposition halo/thin/thick disk seems able to reproduce the observations without additional structures.

Key words. Galaxy: disk–Galaxy: stellar content–Galaxy: structure

1. Introduction

Star count models exploit the color-magnitude diagram in several directions, attempting to reconstruct a coherent picture of our Galaxy. The primary goal is to understand the structure and the relative importance of the various galactic components. In addition, other quantities such as the star formation rate (SFR), the initial mass function (IMF), the chemical composition and the reddening laws can be also tested.

Despite the pioneer successes by Bahcall (see e.g. Bahcall & Soneira 1984) in '80 and despite the extraordinary amount of precise data, not much is known about our Galaxy's structure: the number of Galactic components (halo, bulge, disk, thick disk, etc..), their actual chemical composition and origin are widely debated. Recent large scale surveys (e.g. SDSS, 2MASS, QUEST) have detected the presence of substructures in the outer halo, probably remnants of disrupted galaxies. As for the disk structures, while there is consensus that most of the thin disk population has a dissipative history, the thick disk origin remains contentious. There are (at least) three main processes which are now proposed to be responsible for thick disk formation: 1) *External origin* -the stars are accreted from outside, during mergings with satellite galaxies, 2) *Induced event*-the thin disk has been puffed up dur-

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ing close encounters with satellite galaxies, 3) *Evolutionary event*-the thick disk settled during the collapse of the protogalactic cloud, before the thin disk had formed.

Given this variable scenario, it is intriguing to learn about more or less pronounced sequences (see Conn et al. 2007) crossing the CMDs at low galactic latitudes. However, fitting these features in a self-consistent scenario is rather challenging. For instance, a wrong metallicity and a complex reddening distribution can both conspire to bias the result. Moreover, in order to detect a possible stellar over-density, it is essential to have an idea, at least partial, of the underlying galactic structure. In other words, one must know how the "average" Galactic CMD should look like especially close to the galactic plane. A way out could be to overcome our ignorance by observing symmetrical directions relative to the plane (as in Conn et al. 2007). Next, invocating a north-south symmetry, the observed CMDs should indicate if we are facing a real over-density or not. However, also this option is a Pandora's box: is the Galaxy symmetrical? Is the Galaxy warped (see López-Corredoira et al. 2007)? Can asymmetrical reddening distributions or stellar chemical gradients mimic asymmetrical star counts?

This paper discusses the capability of a galactic synthesis model to interpret the star counts at low galactic latitudes. We propose to change the point of view with respect to the photometric parallax procedure: we do not create a main sequence template attempting to recover the underlying distribution, but we try to translate the current knowledge of the galactic populations (thin disk, thick disk and halo) in synthetic CMDs, in order to see if they are compatible (and at which degree) with the observed CMDs. We try to answer the following question: do the many uncertainties on the Milky Way structure allow to explain the observed CMDs without invoking anomalies? We don't pretend to suggest alternative scenarios, but only to argue that one cannot infer unique results.

Taking advantage of the deep and wide field photometry acquired with the CFH telescope, whose original targets were open clusters close to the galactic plane (Kalirai et al. 2001-a,b,c), we can study the disk structures for several kpc before flowing in a pure halo sample. These low latitude regions are often avoided by star count analysis for their high obscuration. Hence, the published results suffer a kind of bias: most of the investigations are devoted to the study of the disk scale heights and the halo structure, typical information available at intermediate to high galactic latitudes, whilst, the disk scale lengths are often neglected.

The results we find in literature are extremely variable, ranging from 2 kpc to 5 kpc for the thick disk scale length. Some of these studies provide evidence for a thick disk/thin disk decomposition with similar scale lengths; others do not. As an example of the former, Robin et al. (1996) and others find 2.5 kpc for the thin disk and 2.8 kpc for the thick disk. On the other hand, Ojha (2001) finds a thin disk scale length of 2.8 kpc and a thick disk of 3.7 kpc. From edge-on disk galaxies, Yoachim & Dalcanton (2006) find support for thick disks larger than the embedded thin disks. Moreover, Parker, Humphreys & Larsen (2003) argue that the thick disk is not axisymmetrical.

The main issue is whether the thick disk is an independent structure. Although chemical investigations indicate a different α-elements history for the thick disk, suggesting it is a separate component, most of these studies must assume a well defined kinematical signature, neglecting stars with intermediate kinematics. A marked scale height difference between the two disks (250 pc versus 1000 pc), a well established result, does not exclude a heating origin. The radial scales could in principle distinguish among different formation scenarios: N-body simulations suggest that a heating mechanism can increse the scale height, but it hardly produces a longer scale length.

2. Data selection

We have examined three low latitude fields, observed with the CFH telescope, corresponding to the position of the open clusters NGC6819

(l = 73.98, b = 8.48), NGC7789 (l = 115.5, b = −5.38) and NGC2099 (l = 177.63, b = 3.09). These data, which were originally aimed to the study of cluster white dwarfs, represent very deep windows in the thin and thick disk. We have selected these three fields out of the twenty currently available from the BOCCE (Bologna Open Clusters Chemical Evolution) project (see Bragaglia et al. this volume), because they are the deepest and cleanest ones.

To select bona fide field stars, we have cropped the CMDs below the cluster main sequence: this region is different for each field (as shown in the upper panel of Figures 1, 2, 3), mostly because the boundary conditions are not the same (position of the cluster, reddening distribution, etc..). To increase the sensitivity to the structural parameters, each region has been further divided into subregions. The chosen "grid" is a compromise, since:

- including also red stars gives a better statistics
- a narrow color range shortens the mass spectrum of the stellar populations, making the adopted SFR and the IMF less critical assumptions
- focusing only on blue stars preserves the B-magnitude completeness.

The bright and faint limits in magnitude permit to reach two goals: avoid cluster stars, but guarantee the sample completeness.

Unfortunately, in the directions $l = 115.5, b = -5.38$ and $l = 73.98, b = 8.48$, most of the thin disk population is unavoidably lost during the selection: here, the bulk of thin disk stars is close to the Sun, therefore, field and cluster stars share similar CMD positions. Although this is a strong limitation for the thin disk analysis, these data still represent a unique chance to study the thick disk structure. In fact, few, if any, of the sources with magnitude fainter than $V = 18$ are likely to be physically associated to the cluster. Thanks to the excellent photometry, we can exploit the CMDs down to $V = 22$. At this magnitude, according to simulations, we have chances to trace the radial length of the thick disk. Different is the situation of the anticenter field ($l = 177.63, b = 3.09$). There the proximity of the galactic plane offers a deep snapshot of the outer thin disk, but at the expenses of the information about the thick disk. Combining the three lines of sight is an effective test on the galactic models.

Finally, the CMD density of these stars reflects the matter distribution along the line of sight: the luminosity function is more sensitive to the galactic structure, while the color distribution is a major discriminant for age/metallicity/reddening combinations.

3. The model

Both the thin and the thick disk components are assumed to follow a double exponential profile, with radial and vertical scales. Because of the low latitude, the lines of sights of our fields are not much informative about the vertical structure. We have adopted mean values of 250 pc and 1 kpc (which are comfortably within the literature range), respectively, for the thin disk and the thick disk. We let the radial scales vary. Halo and thick disk local densities are anchored to the solar neighborhood and expressed as a fraction of the thin disk density. In particular, the local halo fraction is fixed to be 0.0015, while the thick disk value is a free parameter. The stellar halo is characterized by a De Vaucouleurs density law with a half-light radius of 2.6 kpc. Although our data are marginally sensitive to the halo structure because of their low Galactic latitude, simulations indicate that this component is required to improve the quality of the fit.

In conclusion, our galactic model relies on three free parameters, namely the two scale lengths (thin and thick disk) and the local thick disk normalization.

A complete list of model ingredients is indicated in Table 1. For each component, the SFR is assumed constant. The recent thin disk SFR is chosen to reproduce the blue edge of the CMD.

The IMF is a power law with a Salpeter exponent. Masses and ages are randomly extracted from the IMF and the SFR, and the colors are interpolated using the Pisa evolutionary library (Cariulo, Degl'Innocenti & Castellani 2004). Once the absolute photometry is cre-

Table 1. Model parameters. The X-symbol indicates a variable quantity.

	Thin disk	Thick disk	Halo
SFR(Gyr)	X-6	10-12	12
Z	0.02	0.001-0.006	0.0004
H-scale(pc)	250	1000	/
Radial scale(pc)	X	X	2600
$[\rho/\rho_{Thin}]_\odot$	1	X	0.0015

ated, the line of sight is populated according to the density profiles. Finally, a reddening correction is introduced. To reduce the Poisson noise, the model CMDs are built from ten times larger samples. For stars brighter than V=22, photometric errors do not exceed 0.01 mag and the completeness in V is around 80% (see Kalirai et al. 2001-b,c), thus the simulated CMDs can be directly compared with the data without blurring or corrections.

Finally, to evaluate the match quality of a given model, a Kolmogorov Smirnov test is carried out to investigate both the color distribution in each subregion and the luminosity function of the whole box. Only models giving a KS-probability higher than 0.001 are retained.

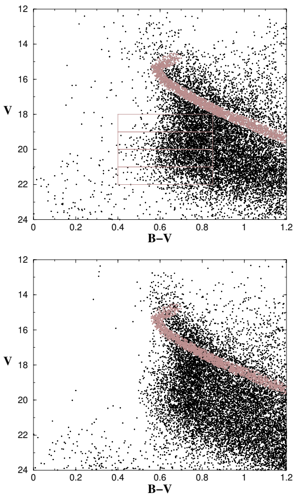

Fig. 1. Top panel: the observational CMD in the direction of NGC6819. The location of the explored subregions is indicated by the boxes. Bottom panel: an acceptable synthetic diagram. The radial scales for thin disk and thick disk are respectively 2500 pc and 3700 pc. The local thick disk normalization is 7%.

4. Preliminary results and future work

The lower panels of Figures 1, 2, 3 show the simulated diagrams which best reproduce the observed CMDs. The parameters we have used are quite similar, suggesting that *a common solution exists*: a canonical Galactic model following the classical decomposition thin disk, thick disk and halo can satisfy the CMD constraints. We also give the reddening distribution. As expected, a constant reddening (close to the value[1] estimated for the cluster) is required for the directions NGC6819 and NGC7789. Hence, the geometry of these fields confines the dimming material very close to the Sun. For NGC2099, instead a reddening function of the heliocentric distance is needed. Our result on the reddening distribution is shown in Figure 4: the reddening varies following an irregular pattern, which is not consistent with a classical exponential profile.

Also the required thin disk SFR deserves a comment. Results for NGC6819 and NGC7789 suggest that a still ongoing thin disk star formation is inconsistent with the observed CMD (a similar conclusion was found by Vallenari, Bertelli & Schmidtobreick 2000). In fact, to reproduce the blue edge at magnitudes fainter than V=18, the thin disk activity must have switched off about 1-1.5 Gyr ago. This result, however, does not rule out the possibility that the recent star formation be confined on vertical scales shorter than

[1] For NGC7789 it is also significantly lower than the Schlegel et al. 1998 map prediction.

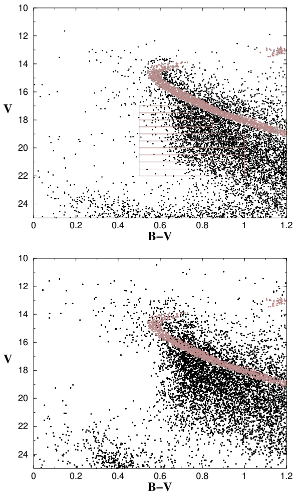

Fig. 2. NGC7789. As in figure 1. Here the radial scales for thin disk and thick disk are respectively 2500 pc and 3500 pc. The local thick disk normalization is 6%.

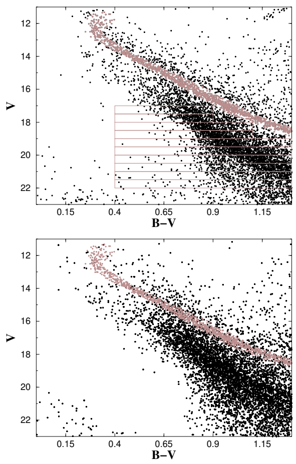

Fig. 3. NGC2099. As in figure 1. Here the radial scales for thin disk and thick disk are respectively 2200 pc and 3300 pc. The local thick disk normalization is 5%.

100 pc. Indeed, including a very thin young component we can reproduce the bright and sparse blue plumes which are present in the CMDs of both the NGC6819 and NGC7789 fields.

Our simple model appears to match the observations, the few directions we have pre-

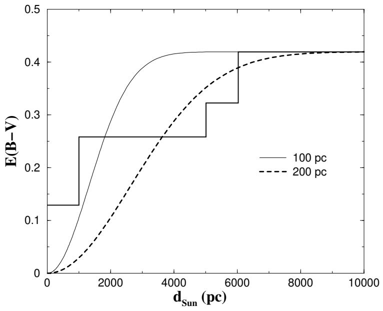

Fig. 4. The recovered reddening law for the field of NGC2099 as a function of the heliocentric distance. Exponential distributions with vertical scales of 100 and 200 pc are also shown.

vent a reliable conclusion and more directions would be needed. A systematic exploration of the full parameter space, including also the scale heights, will be the subject of a forecoming paper.

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References

Bahcall, J. N. & Soneira, R. M. 1984, ApJS, 55, 67
Cariulo, P., Degl'Innocenti, S. & Castellani, V. 2004, A&A, 421, 1121
Conn, B. C., Lane, R. R., Lewis, G. F., et al. 2007, MNRAS, 376, 939
Kalirai, J. S., et al. 2001-a, AJ, 122, 257
Kaliral, J. S., et al. 2001-b, AJ, 122, 266
Kalirai, J. S., et al. 2001-c, AJ, 122, 3239
López-Corredoira, M., Momany, Y., Zaggia, S., Cabrera-Lavers, A. 2007, A&A, 472,47
Ojha, D. K. 2001, MNRAS, 322, 426
Parker, J. E., Humphreys, R. M., & Larsen, J. A. 2003, AJ, 126, 1346
Robin, A. C., Haywood, M., Creze, M., Ojha, D. K., Bienayme, O. 1996, A&A, 305, 125
Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, ApJ, 500, 525
Vallenari, A., Bertelli, G. & Schmidtobreick, L. 2000, A&A, 361, 73
Yoachim, P. & Dalcanton, J. J. 2006, AJ, 131, 226