Clues on the Milky Way disc formation from population synthesis simulations

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Outline

• Introduction
• Modelling approach
• Efficient model parameter space exploration
• Results on thick disc formation
• Results on thin disc outer structures: warp, flare and scale lengths
• Confronting the new model to spectroscopic surveys: RAVE, APOGEE
• Conclusion and perspectives
Preambule

- Galactic archeology much more difficult than cosmology: they have distances and ages, all at the same time! (z)

- How can we do Galactic archeology without good distances and ages? we do! (at least we try…)

- The Gold Age: Gaia, Corot-Kepler-PLATO
Introduction

- Surveys: photometric, spectroscopic, multi-wavelength, and now asteroseismic!
- Need to combine them in a global analysis to gain in understanding complex evolution of the Milky Way
- \( \Rightarrow \) modelling
Population synthesis

Simulations of surveys

\[ N = \int_0^\infty \rho(r) \phi(M) \Omega r^2 \, dr \]

or

\[ N = \sum_{i=1}^{N_{\text{pop}}} \int_0^\infty \rho_i(r) \phi_i(M) \Omega r^2 \, dr \]

\( \phi(M_v, \text{Teff}) \) for a thin disc with cste SFR over 10 Gyr

\( \varphi(x,y,z) \) : density laws constrained by dynamics (Bienaymé et al, 1987)

3D extinction model

Simulate observational errors
Population Synthesis Modelling

- Population synthesis approach: many parameters but more understanding
- **Statistical treatment**: no individual distances and ages, but for groups of stars
- Link between scenarios and observations
- Confront scenarios with surveys (combined, different wavelengths, methods)
- **Increasing** complexity (start simple…)
- Confronted to many observables: magnitudes, colors (many bands), proper motions, radial velocities, Teff, logg, [Fe/H],[alpha/Fe], asterosismic parameters in the future
Constraining parameters

- Statistical methods to constrain parameters (do not be satisfied with a solution!)
- Explore parameter space with efficient methods (MCMC, GA, ...)

De Jong et al, 2010
2 applications

- Study of thick disc and halo from SDSS+2MASS (ABC-MCMC) *Robin, Reylé et al, 2014*

- Preliminary study the outer disc from 2MASS (GA) *Amores, Robin, Reylé, 2015 to be subm*
Thick disc and halo
From SDSS + 2MASS

- Fit SDSS fields with no streams (photometry) (F1,F2,F3,F4 patches)
- Add 2MASS fields at intermediate latitudes and a larger longitude range
- MCMC fit, maximum likelihood g.o.f.: halo shape, thick disc shape, age, mean [Fe/H]
Get rid of degeneracies of thick disc scale height

De Jong et al, 2010

Also constraining the scale length and the flare
How long the thick disc formed stars

- Assuming 2 epochs of formation (or a continuity)
- Free parameters for each episode: scale height, length, normalisation, flare
- Try different ages
Fig. A.1. Comparison of the best fit for a different magnitude range, from lines, model with two formation episoc

Fig. A.5. Same as figure A1 for SDSS field at longitude 116°, latitude -51°.
Residuals in CMDs

Single burst

Longer star formation
Thick disc scale height and scale length decreases with time!
Main thick disc: ~10 Gyr about 80-90%, older thick disc 10-15%

<table>
<thead>
<tr>
<th></th>
<th>Old thick disc</th>
<th>Young thick disc</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>12 Gyr</td>
<td>12 Gyr</td>
</tr>
<tr>
<td>scale height (pc)</td>
<td>465.</td>
<td>826.</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>359.</td>
</tr>
<tr>
<td>scale length (pc)</td>
<td>2305.</td>
<td>3077.</td>
</tr>
<tr>
<td>normalisation</td>
<td>1.55</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>1.54</td>
</tr>
<tr>
<td>flare start radius (pc)</td>
<td>9359.</td>
<td>10020.</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>17364</td>
</tr>
<tr>
<td>flare slope (pc/kpc)</td>
<td>0.187</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>0.02</td>
</tr>
<tr>
<td>Lr</td>
<td>-66085.</td>
<td>-60360.</td>
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<tr>
<td>BIC</td>
<td>132035</td>
<td>120566.</td>
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</table>
Robin, Reylé et al, 2014
Thin outer disc

Amores, Robin, Reylé in prep
Age information inside CMDs
- Cannot determine individual ages, but use statistical distributions
- Much easier in a complete sample (photometry)
• 2MASS / BGM via Genetic Algorithm

• In-plane $|b| < 5^\circ$, K/J-K diagrams

• Outer disc: warp, flare, scale length $= f(\text{age})$

• Inner disc: spiral (in prep)

Reylé et al, 2009
Thin disc scale length changing with age, from 4 kpc to \(\sim\) 2 kpc
Warp: slope changing with age + asymmetry

Angle changing with age
~5°/Gyr

Age (Gyr)

Node Angle

20 microas/yr
Relative residuals

Standard Model

New model

longitude

latitude

180° 100° -100° -180°
• **Thick disc formation outside-in**! Lehnert+ 2009, Bournaud + 2009: gas turbulent phase. Explain well the mixing seen in the thick disc abundances in APOGEE (Hayden+ 2014)…. Slow collapse new.

• **Thin disc formation inside-out confirmed.**

• **The warp is a dynamical structure of which we can follow the evolution**

• **The thin disc is flaring as well as the old thick disc**
Figure 10. Scale-height as a function of scale-length for mono-age populations in the 7 simulated galaxies. The scale-heights are measured at a radius of $2R_d$. The colourcode and panel order are the same as in Figure 5. We find that the observed anti-correlation between scale-height and scale-length can be reproduced in the simulations, and does not necessarily imply an absence of mergers.
Bovy et al 2012

Might not be able to see the old thick disc phase due to selections and range of distances
On-going applications to spectroscopic surveys

- Analysis of RAVE data and new kinematical modelling
- Preliminary comparisons with APOGEE data towards the bulge
RAVE survey

- Simulating the RAVE selection function
- $|b| > 20^\circ$ to avoid extinction problems
- Fit kinematic model for the thin and thick disc (ABC-MCMC)
Fitted parameters

- Solar motion
- Circular velocity of the thick disc phases, velocity dispersions
- Thin disc velocity dispersion:
  - $\sigma_w = \sqrt{(a^* \tau + b)}$
- Correct computation of the asymmetric drift out of the plane (O. Bienaymé)
### Preliminary results

<table>
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<tr>
<th>Sun velocities</th>
<th>U</th>
<th>V</th>
<th>W</th>
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<tbody>
<tr>
<td>8.7 ±1.</td>
<td>8.4±1</td>
<td>6.4±1</td>
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</table>

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<tr>
<th>Velocity dispersions</th>
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<tr>
<td><strong>Thick disc 10 Gyr</strong></td>
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<tr>
<td>35±4</td>
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| **Thick disc 12 Gyr** |
| 68±10                | 48±9  | 48±9  |
Thick disc circular velocities

12 Gyr : 175±9 km/s
10 Gyr : 207±4 km/s

- Contraction indicated by the scale lengths and heights (from photometry, star counts)
- Also indicated by the speed up of the circular velocity and by velocity dispersions
- Probable evolution in metallicity as well
• Preliminary application of the target selection in the bulge region

• Test for the new model of thin and thick disc.
Bulge fields: $0^\circ < l < 18^\circ$, $-14^\circ < b < 14^\circ$
Lower latitudes dominated by the bar and thin disc: high $[\text{M/H}]$
Higher latitudes dominated by the thick disc: low $[\text{M/H}]$
$10^\circ < |l| < 20^\circ$

**[M/H]**

Larger longitudes: low metallicity component less prominent
High metallicity component dominated by the inner disc
Varying radial gradients => difficult to reproduce the sharp drop at [Fe/H]=0.5 dex

[Alpha/Fe] well reproduced with a simple model with a thin disc and bar at about solar alpha abundance and a thick disc high alpha abundance.
Summary of conclusions

- The thick disc formed during a long episod of formation, gas turbulence supported but slightly contracting
- The thin disc formed inside out
- The new Thin disc/Thick disc model reproduces well the distributions seen in RAVE and APOGEE
- Explain the complex MDF in the bulge region by combination of a bar (pseudo-bulge) thin and thick discs
Simulated Milky Way seen by Gaia

http://model.obs-besancon.fr
New model available through web service soon