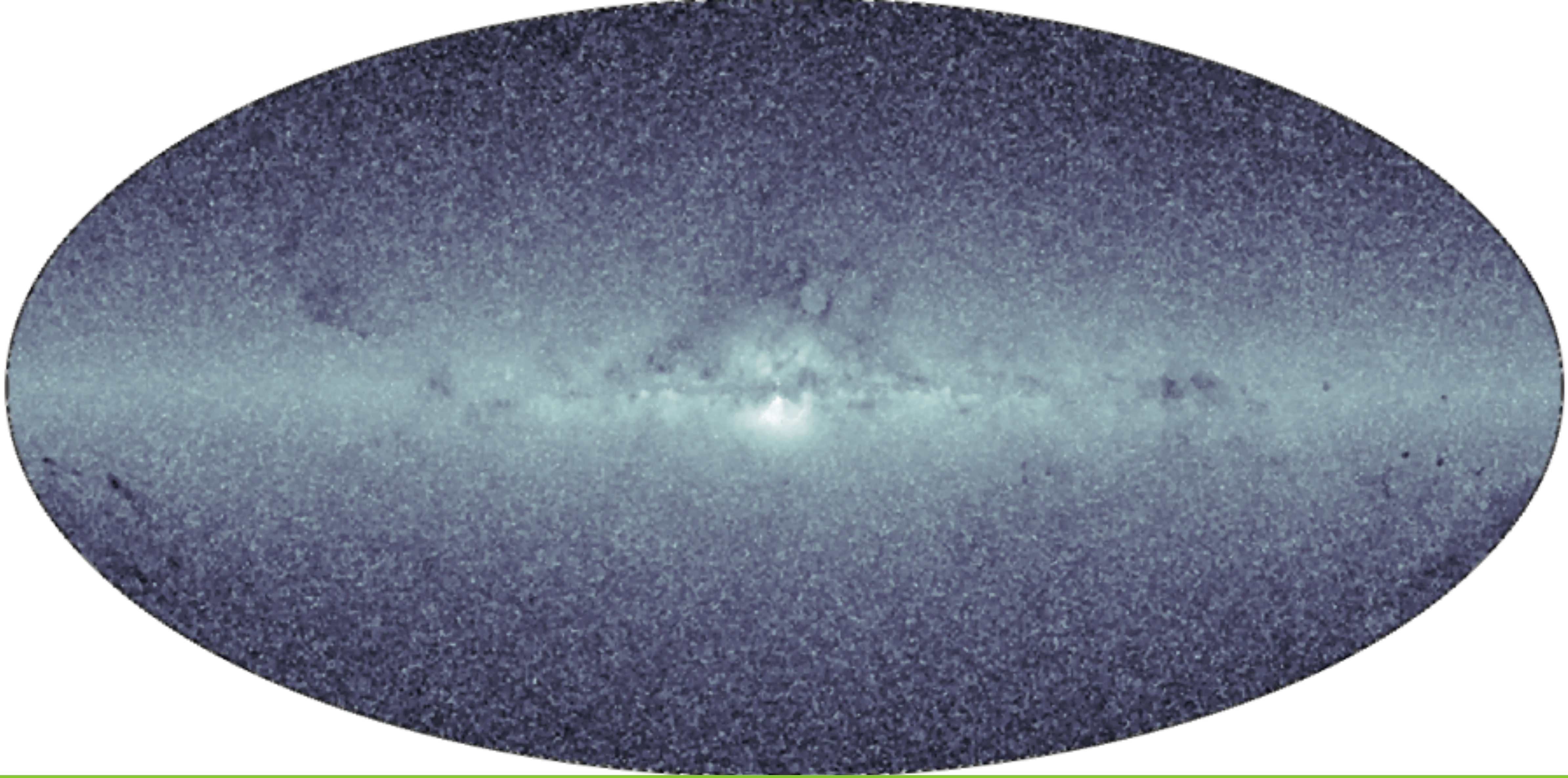

Clues on the Milky Way disc formation from population synthesis simulations

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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 asterosismic !
- Need to combine them in a global analysis to gain in understanding complex evolution of the Milky Way
- => modelling

Population synthesis

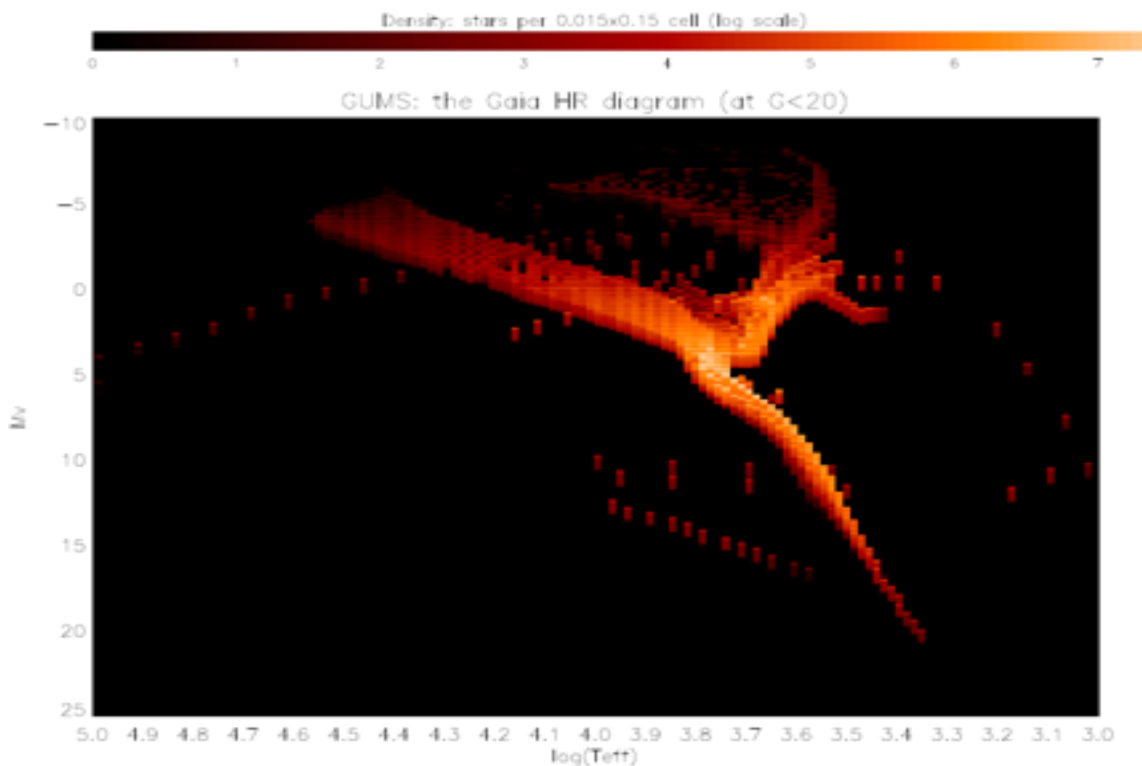
Simulations of surveys

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

or

$$N = \sum_{i=1}^{Npop} \int_0^\infty \rho_i(r)\,\phi_i(M)\,\Omega\,r^2\,dr$$

φ(Mv, Teff) for a thin disc with cste SFR over 10 Gyr →



ρ(x,y,z) : density laws

constrained by dynamics (Bienaymé et al, 1987)

3D extinction model

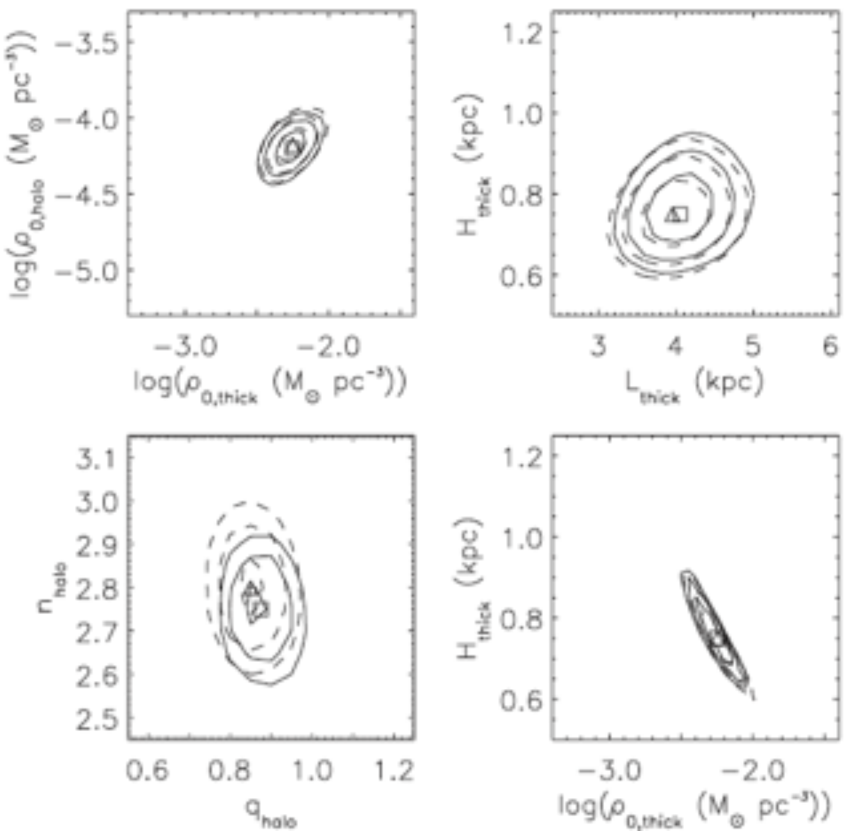
Simulate observational errors

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 paramaters 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, …)



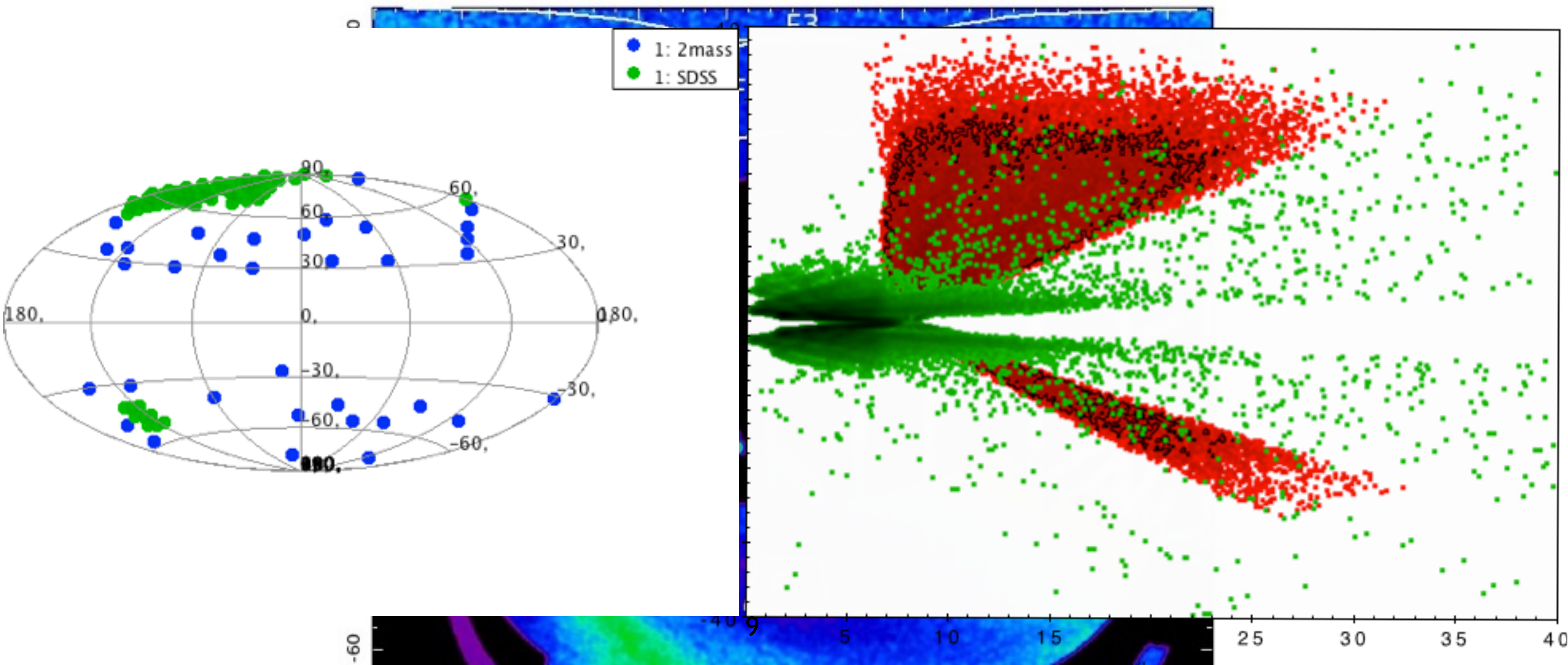
De Jong et al, 2010

2 applications

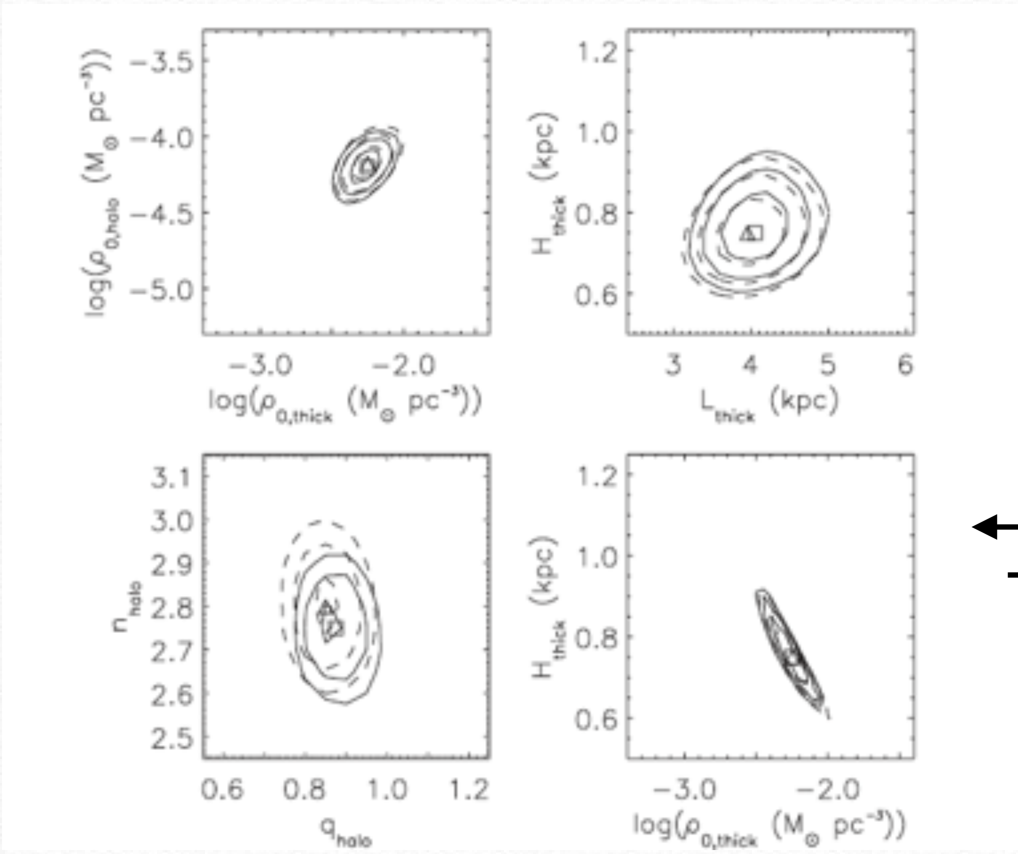
- Study of thick disc and halo from SDSS+2MASS (ABC-MCMC) *Robin, Reylé et al, 2014*
- Preliminary study the outer disc from 2MASS (GA) *Amores, Robin, Reylé, 2015 to be subm*

Thick disc and halo
From SDSS + 2MASS

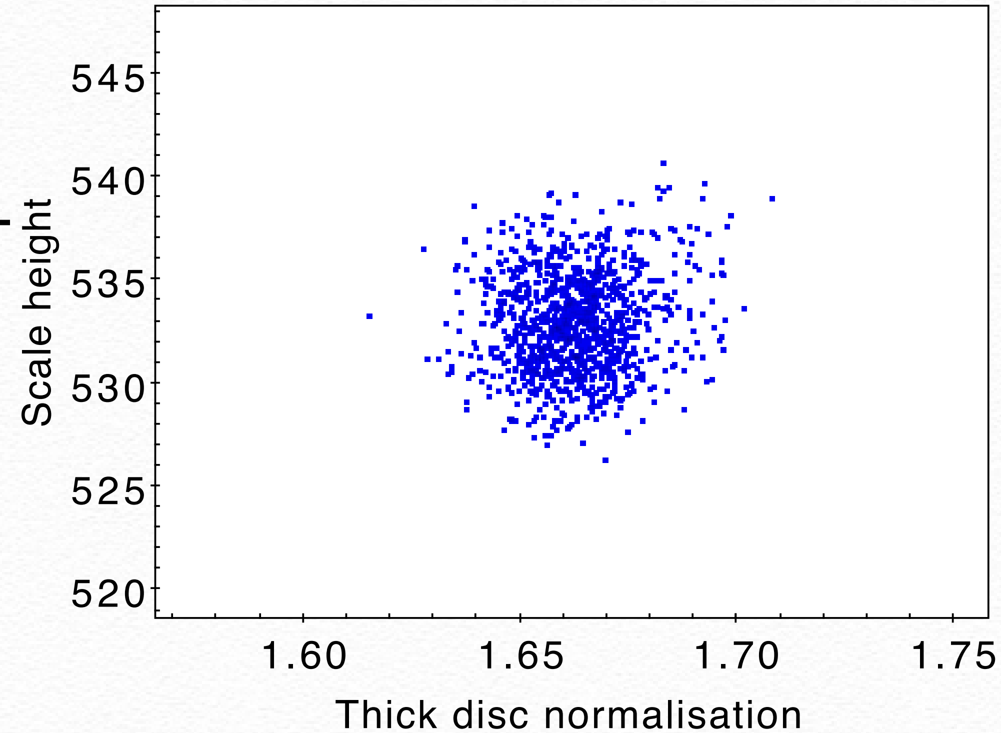
- Fit SDSS fields with no streams (photometry) (F1,F2,F3,F4 patches)
- Add 2MASS fields at intermediate latitudes and a larger longitude range
- MCMC fit, maximum likelihood g.o.f. : halo shape, thick disc shape, age, mean [Fe/H]



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

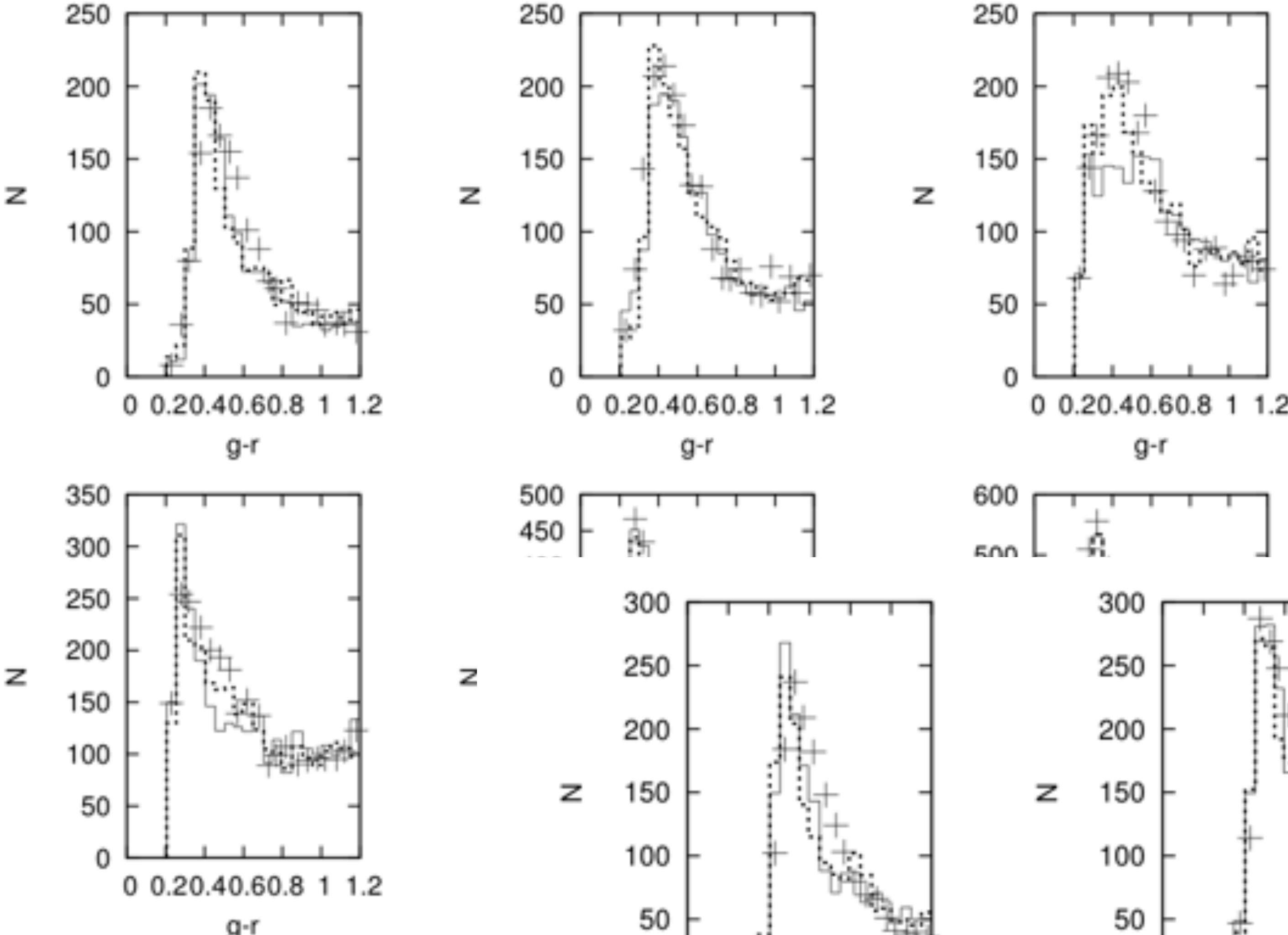


Fig. A.1. Comparison of the best fitnes
for a different magnitude range, from
lines, model with two formation episod

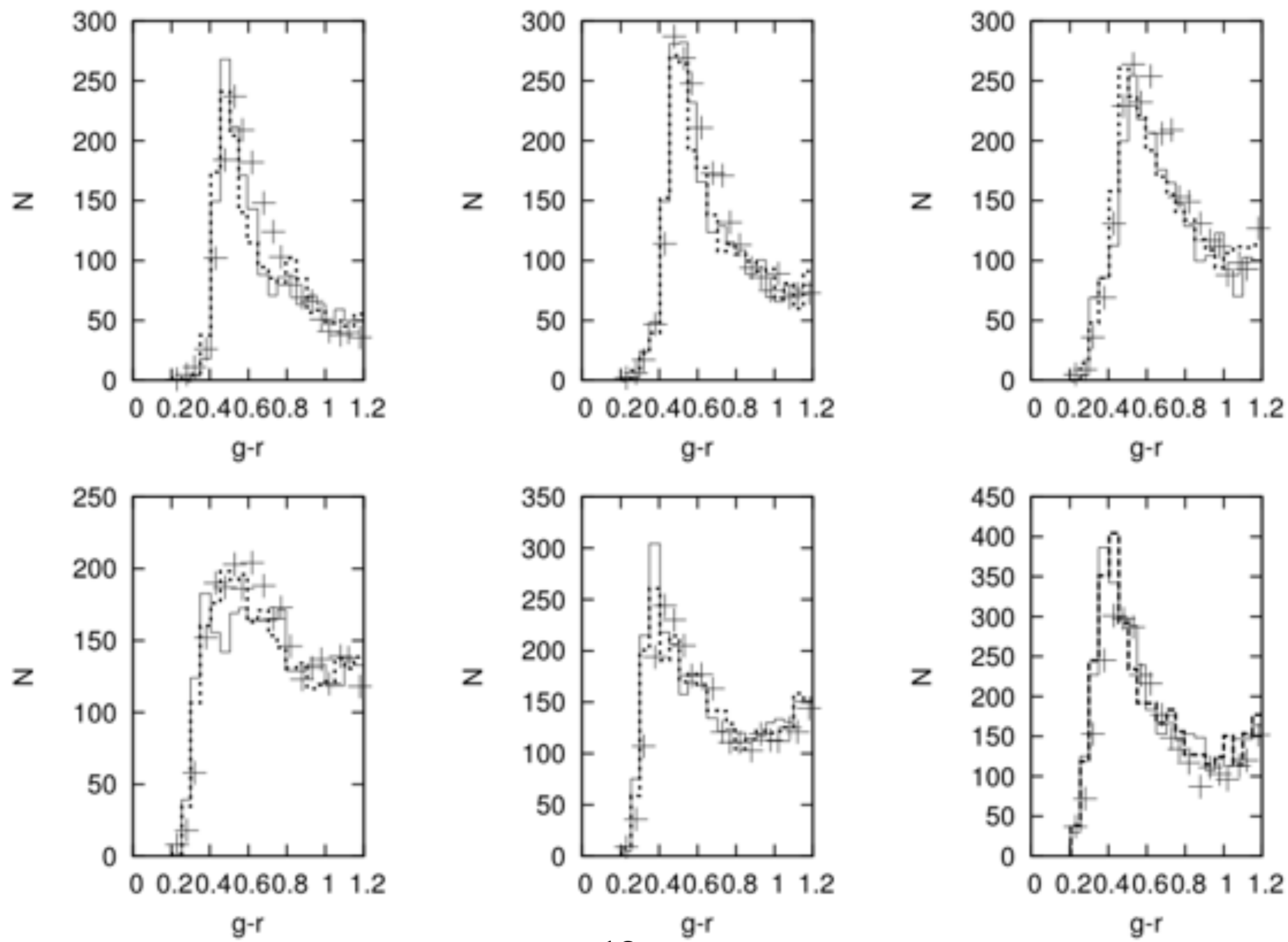
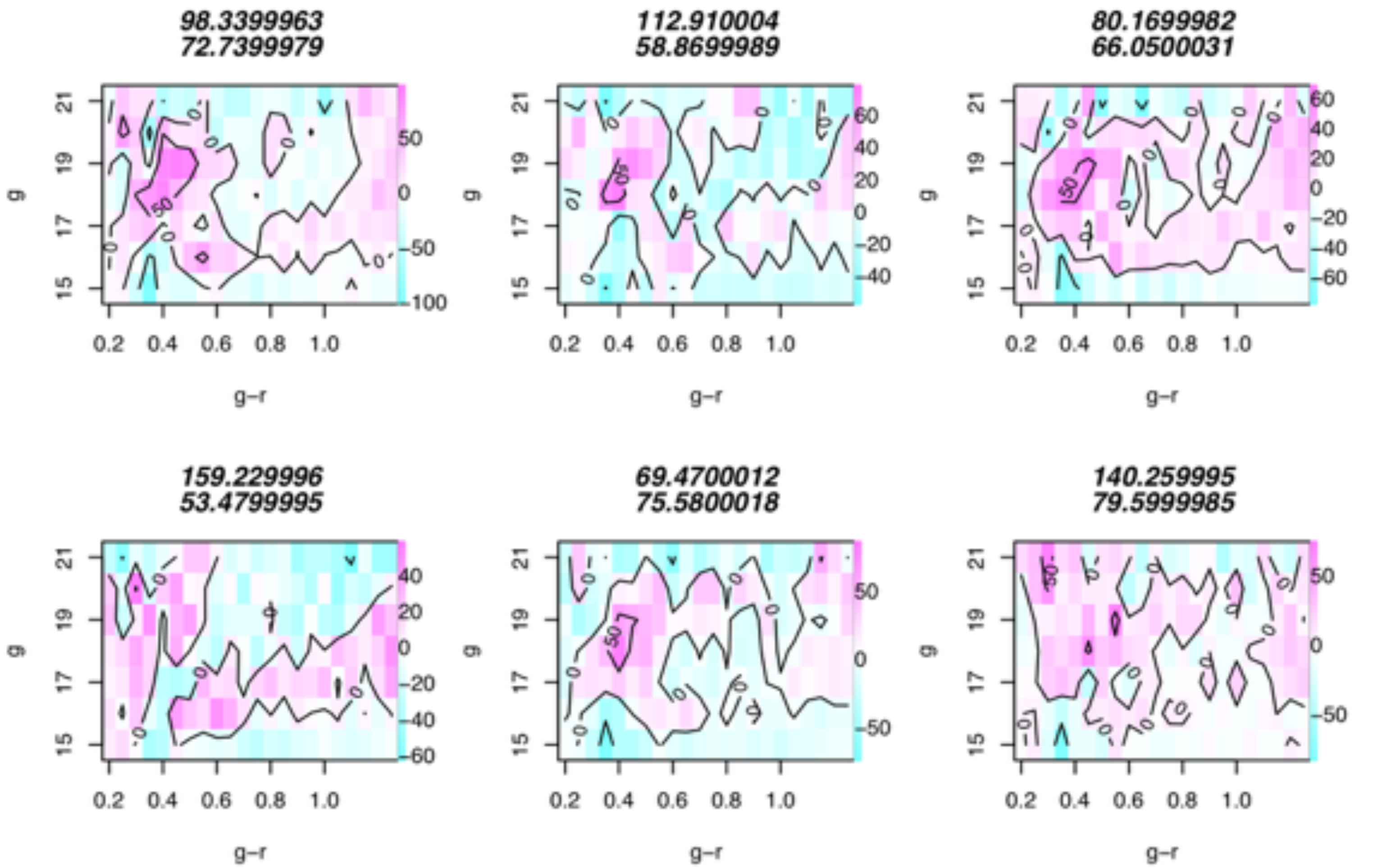


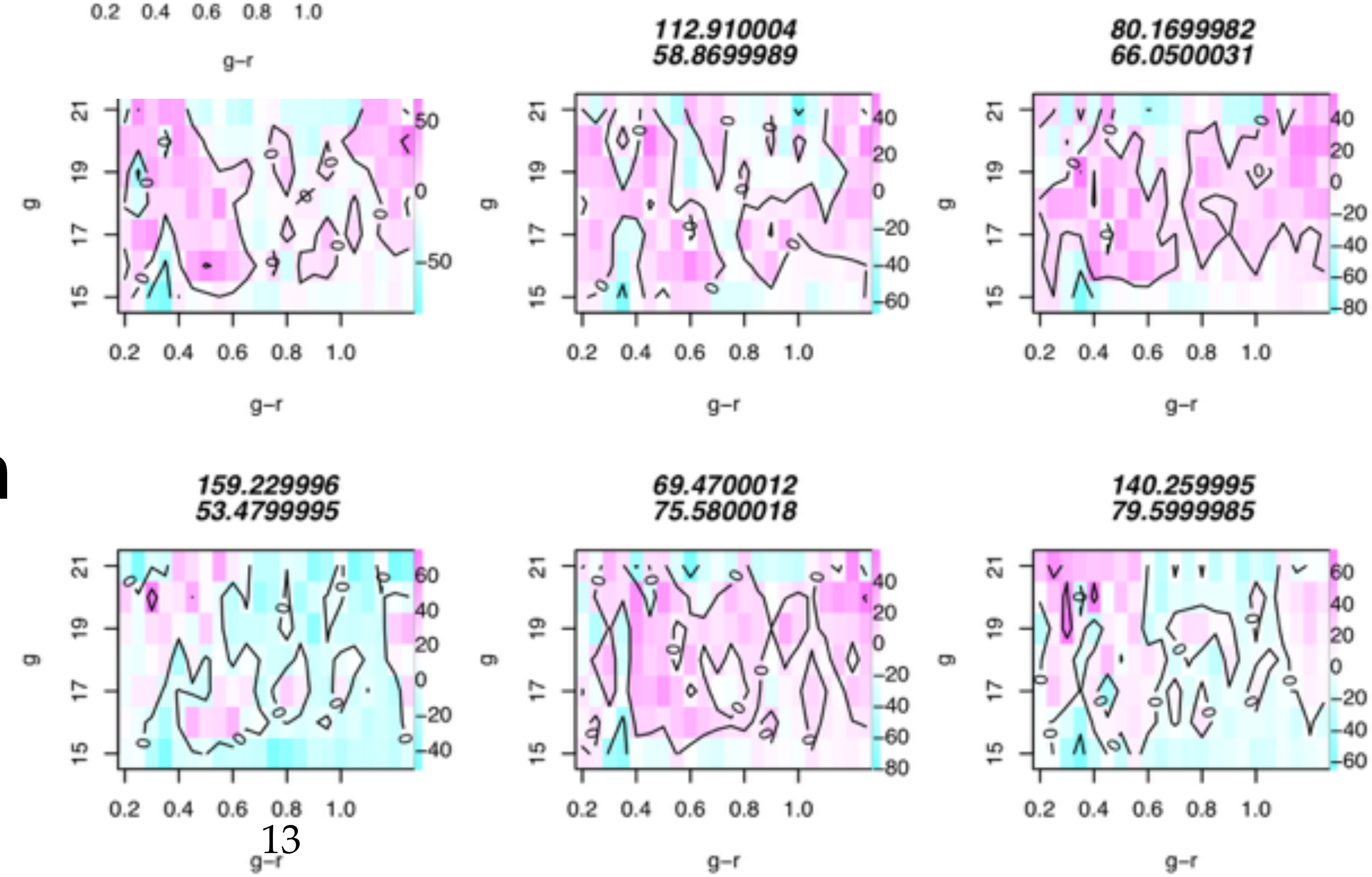
Fig. A.5. Same as figure A1 for SDSS field at longitude 116°, latitude -51°.

Residuals in CMDs

Single burst

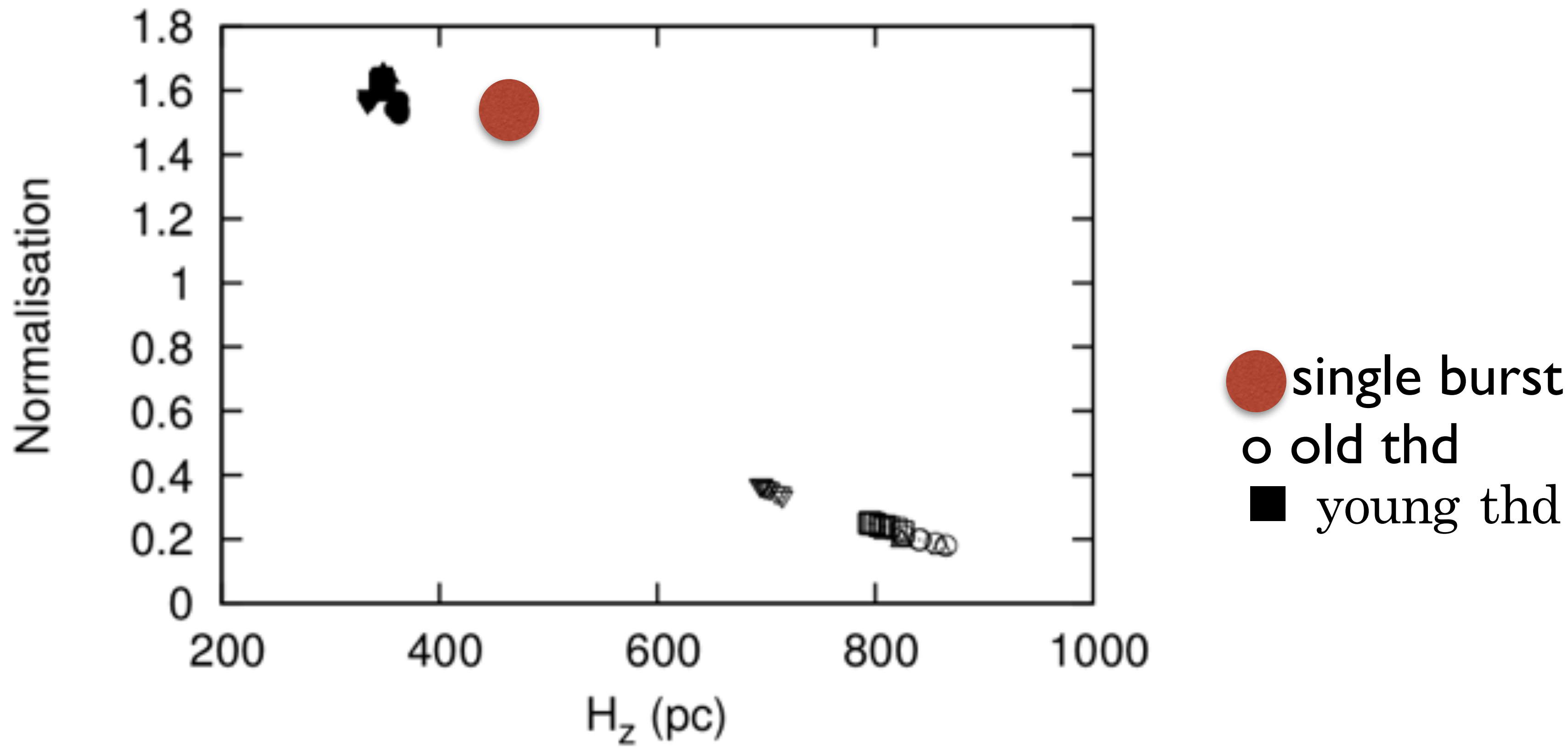


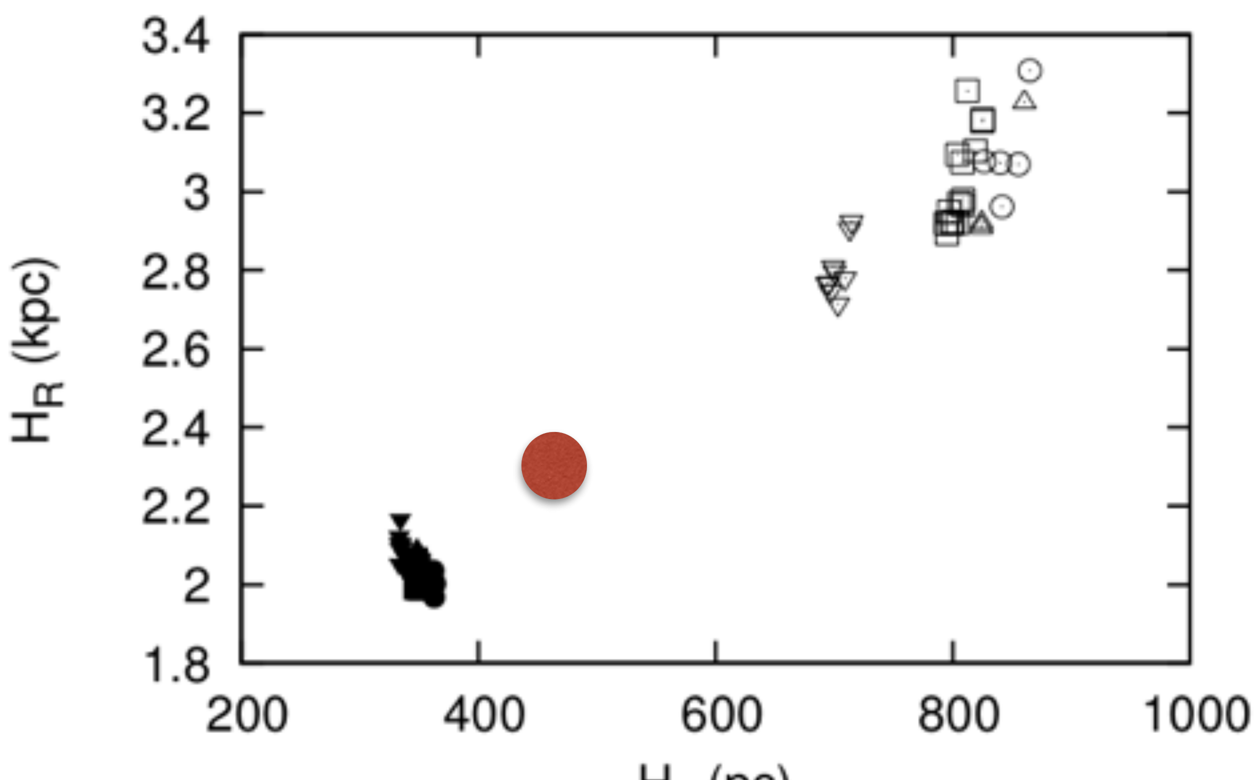
Longer star formation



Old thick disc Young thick disc	12 Gyr -	12 Gyr 11 Gyr	12 Gyr 10 Gyr	11 Gyr 10 Gyr
scale height (pc)	465. -	826. 359.	795. 345.	824. 348.
scale length (pc)	2305. -	3077. 1986.	2919. 2040.	2907 2089.
normalisation	1.55 -	0.21 1.54	0.25 1.63	0.19 1.65
flare start radius (pc)	9359. -	10020. 17364	9543 15340.	9757 14400.
flare slope (pc/kpc)	0.187 -	0.09 0.02	0.06 0.06	0.09 -0.08
Lr BIC	-66085. 132035	-60360. 120566.	-59077 118000.	-61015 121876

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

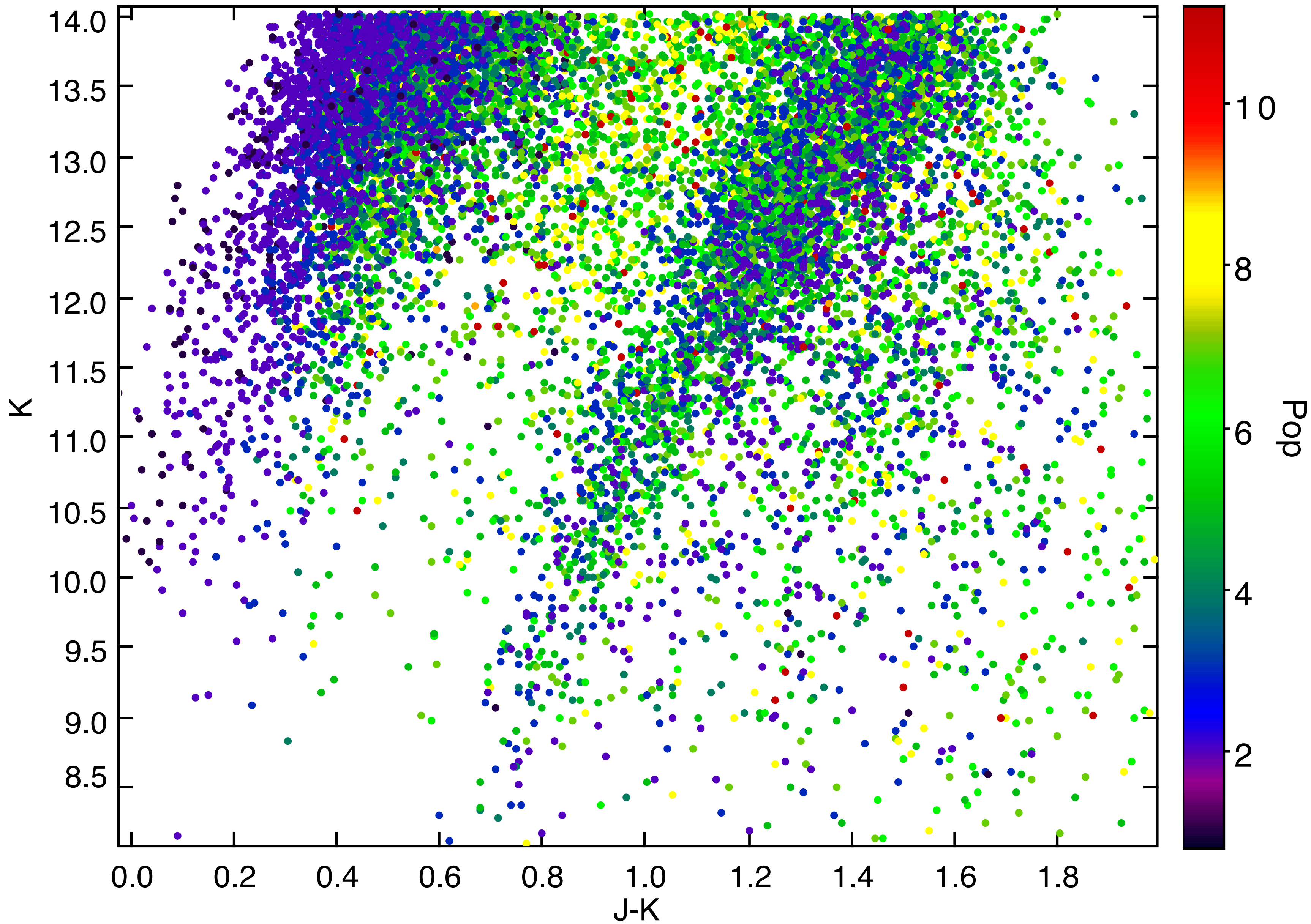




Robin, Reylé et al, 2014

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)

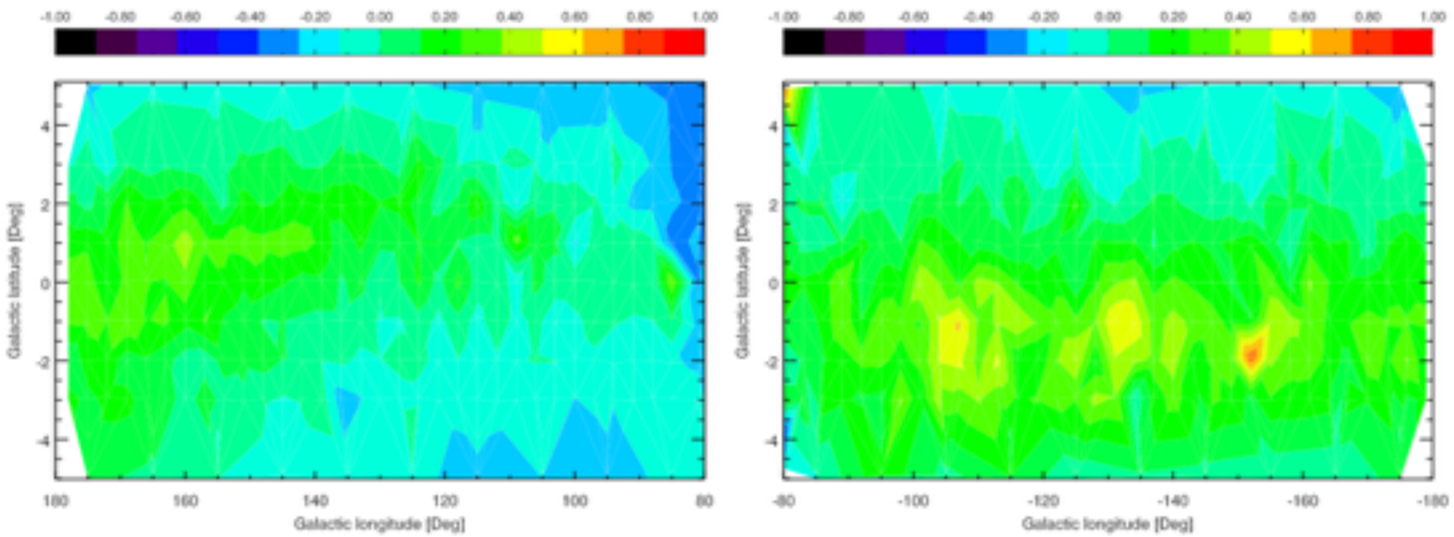
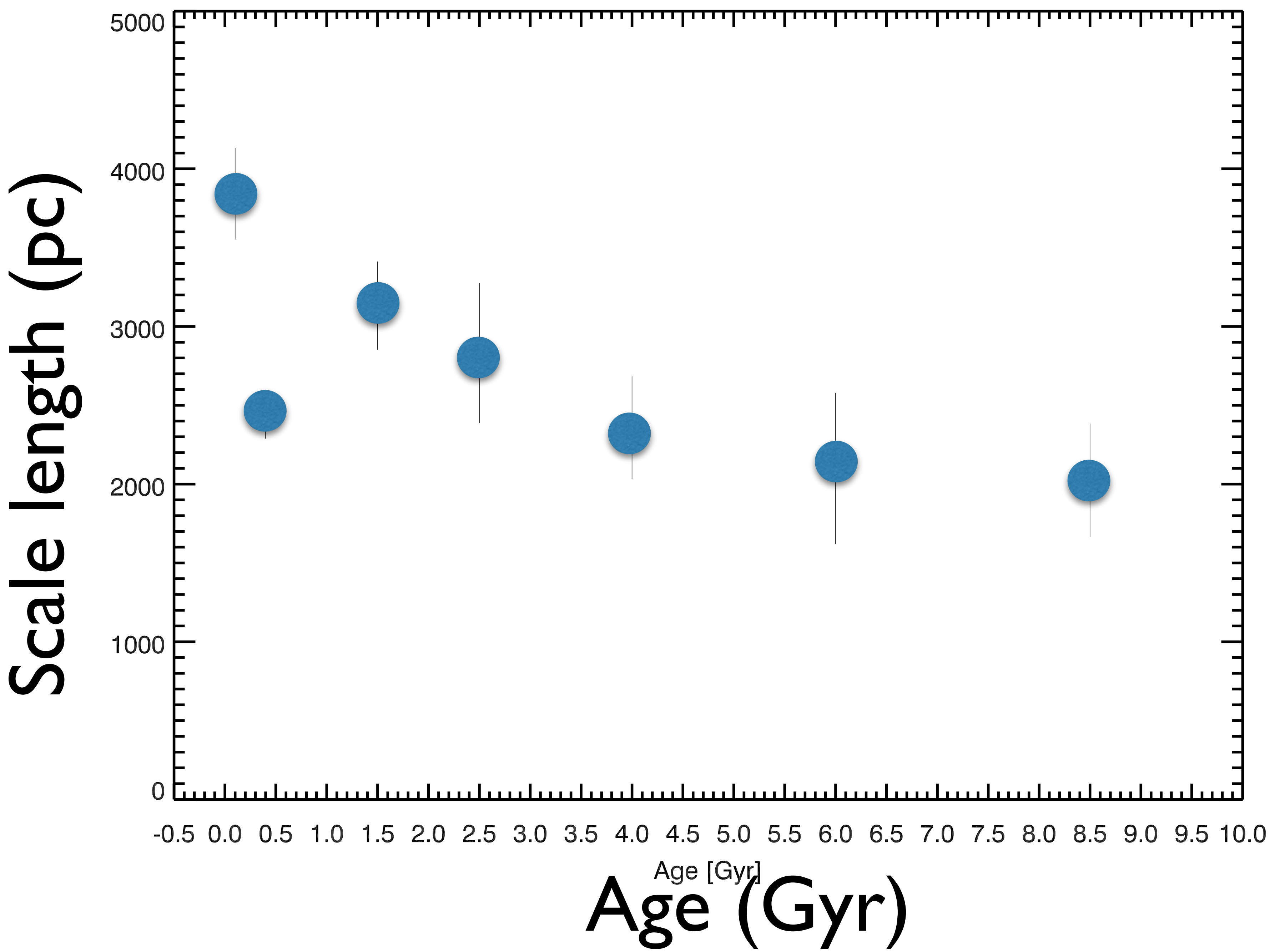


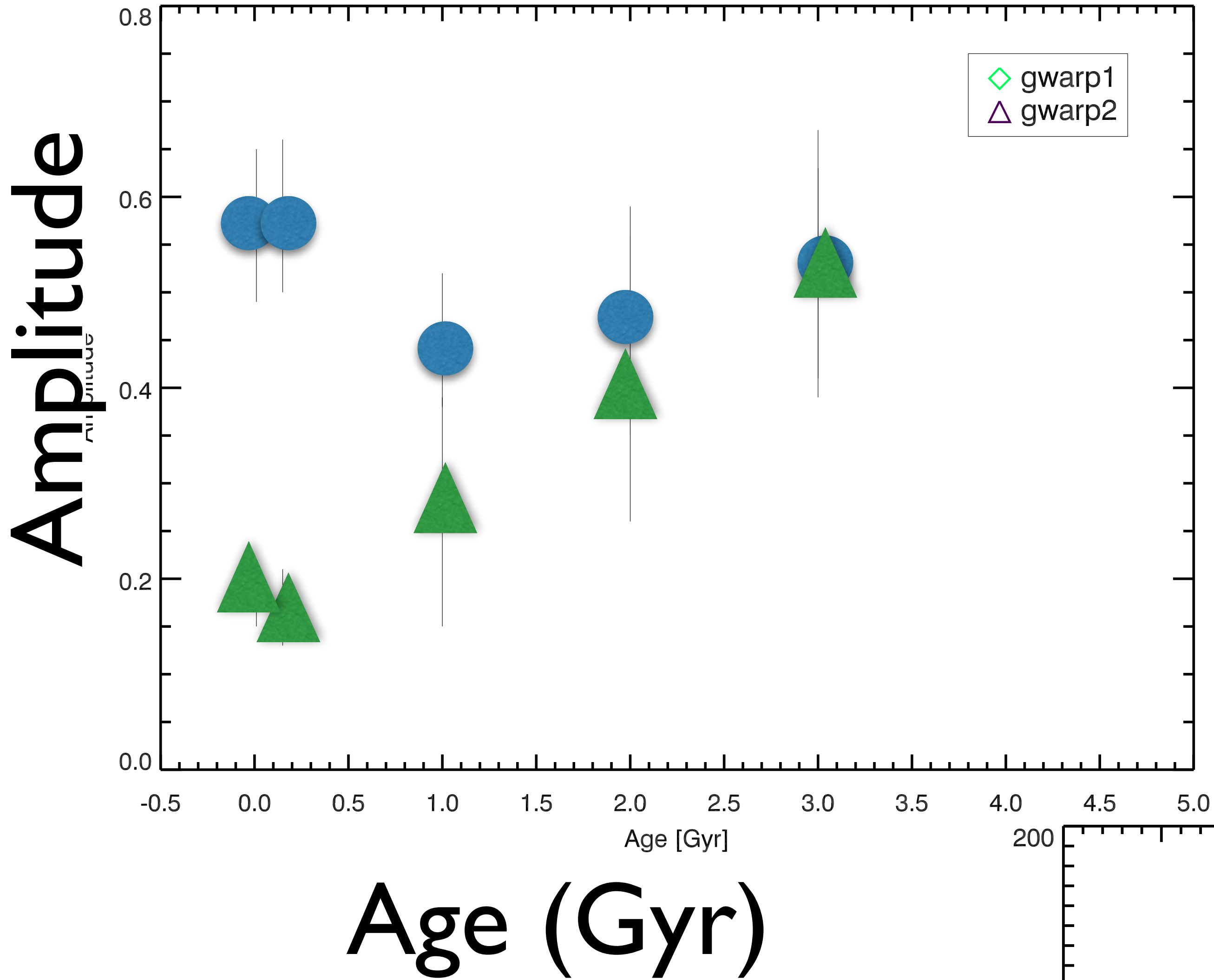
Fig. 3. (ℓ,b) map of relative residuals of the standard Galaxy model $(n_{mod} - n_{obs})/n_{obs}$.

Reylé et al, 2009

- 2MASS / BGM via Genetic Algorithm
- In-plane |b|<5°, K/J-K diagrams
- Outer disc : warp, flare, scale length =f(age)
- Inner disc : spiral (in prep)

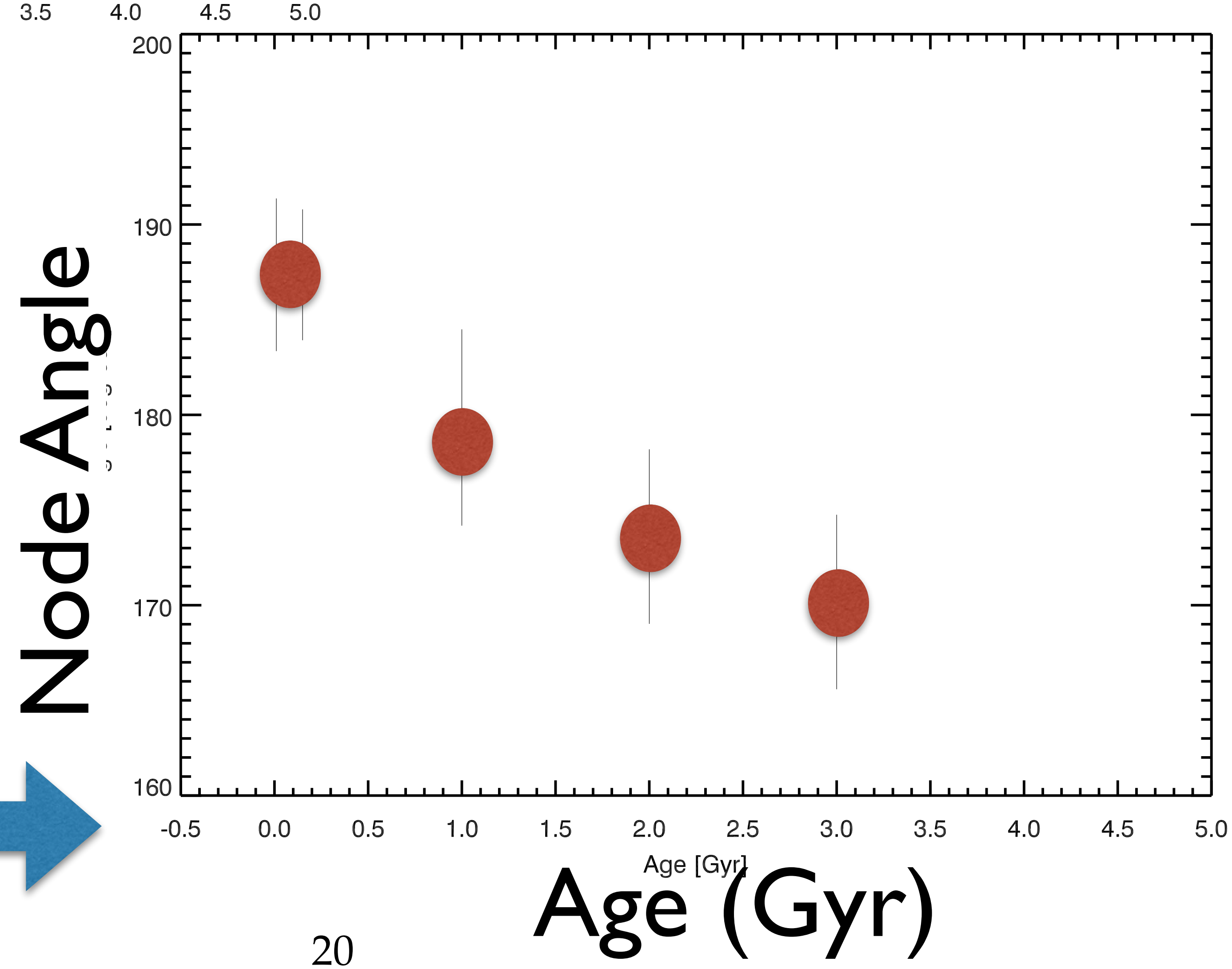


Thin disc scale length changing with age, from 4 kpc to ~2 kpc



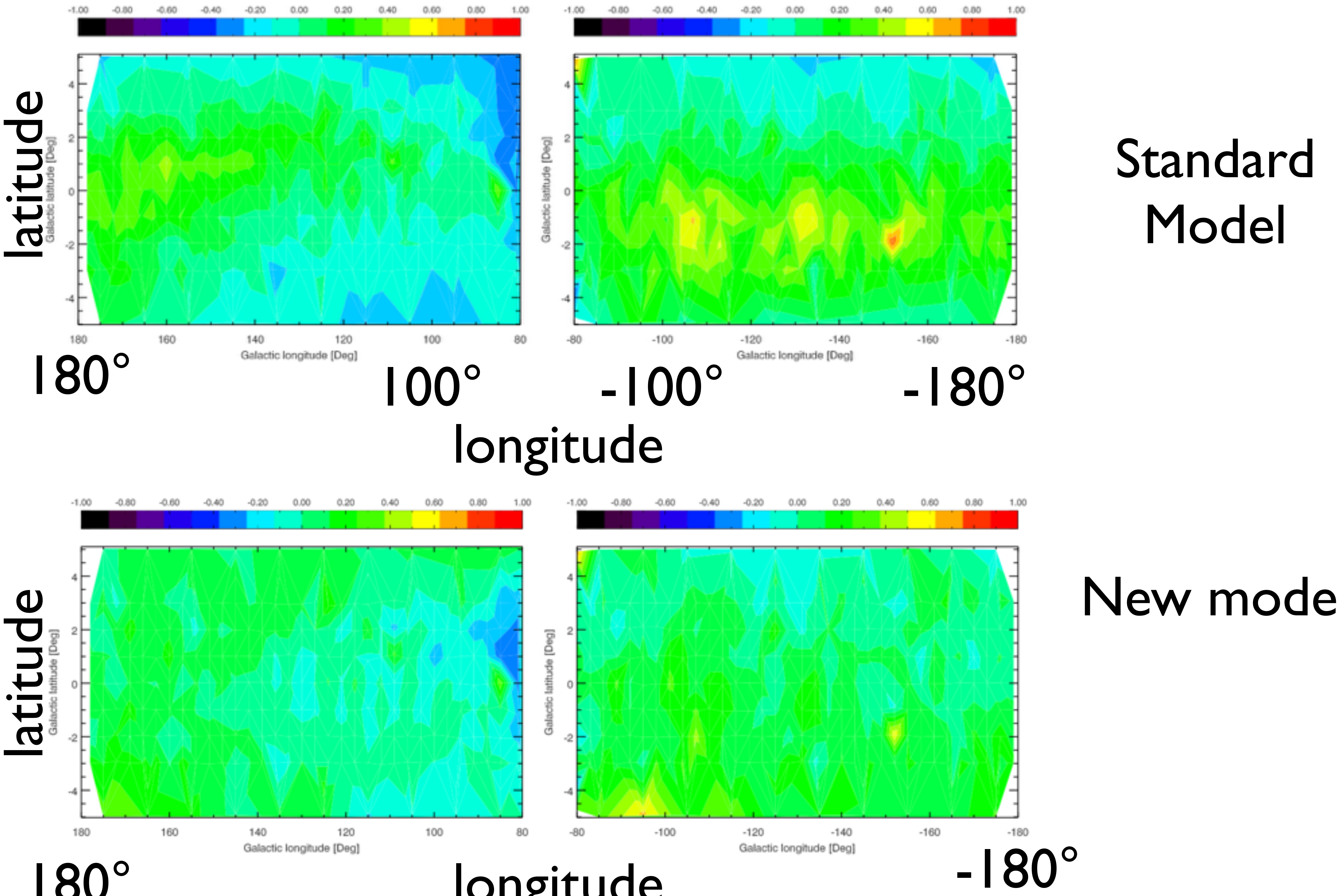
Warp : slope changing with age
+ asymmetry

Angle changing with age
~5°/Gyr



20 microas

Relative residuals



Thin-thick disc relation

- 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

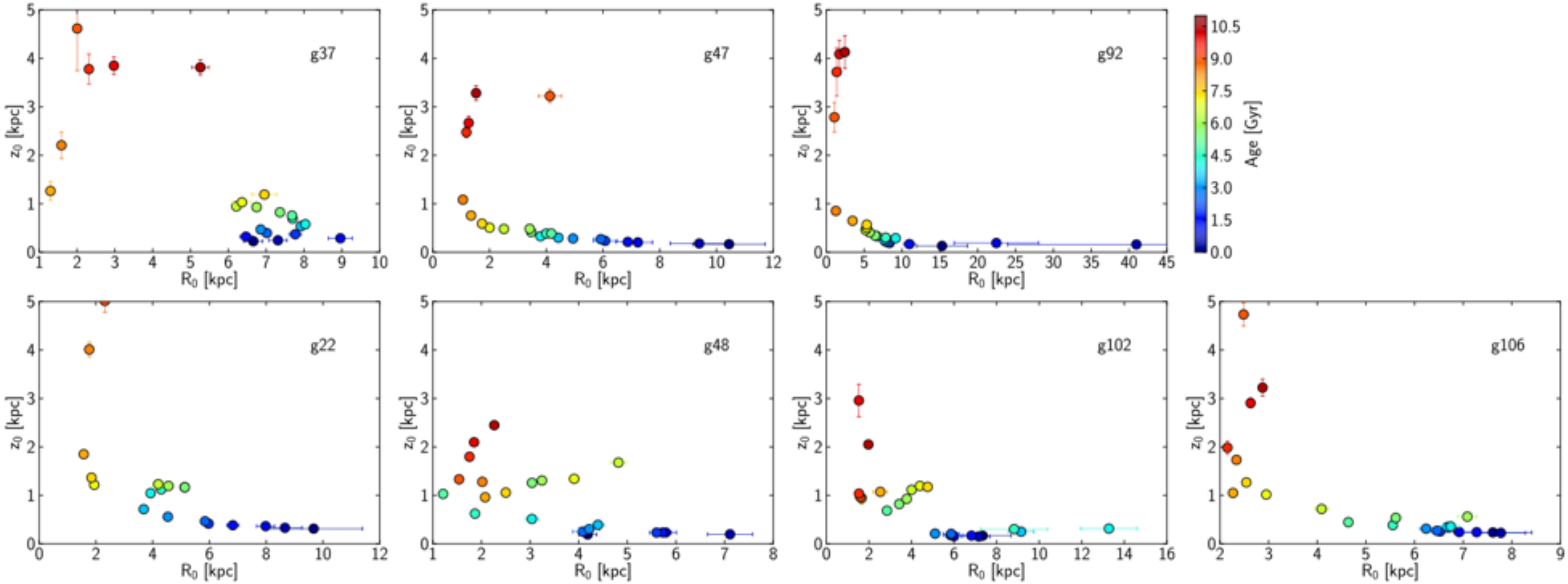
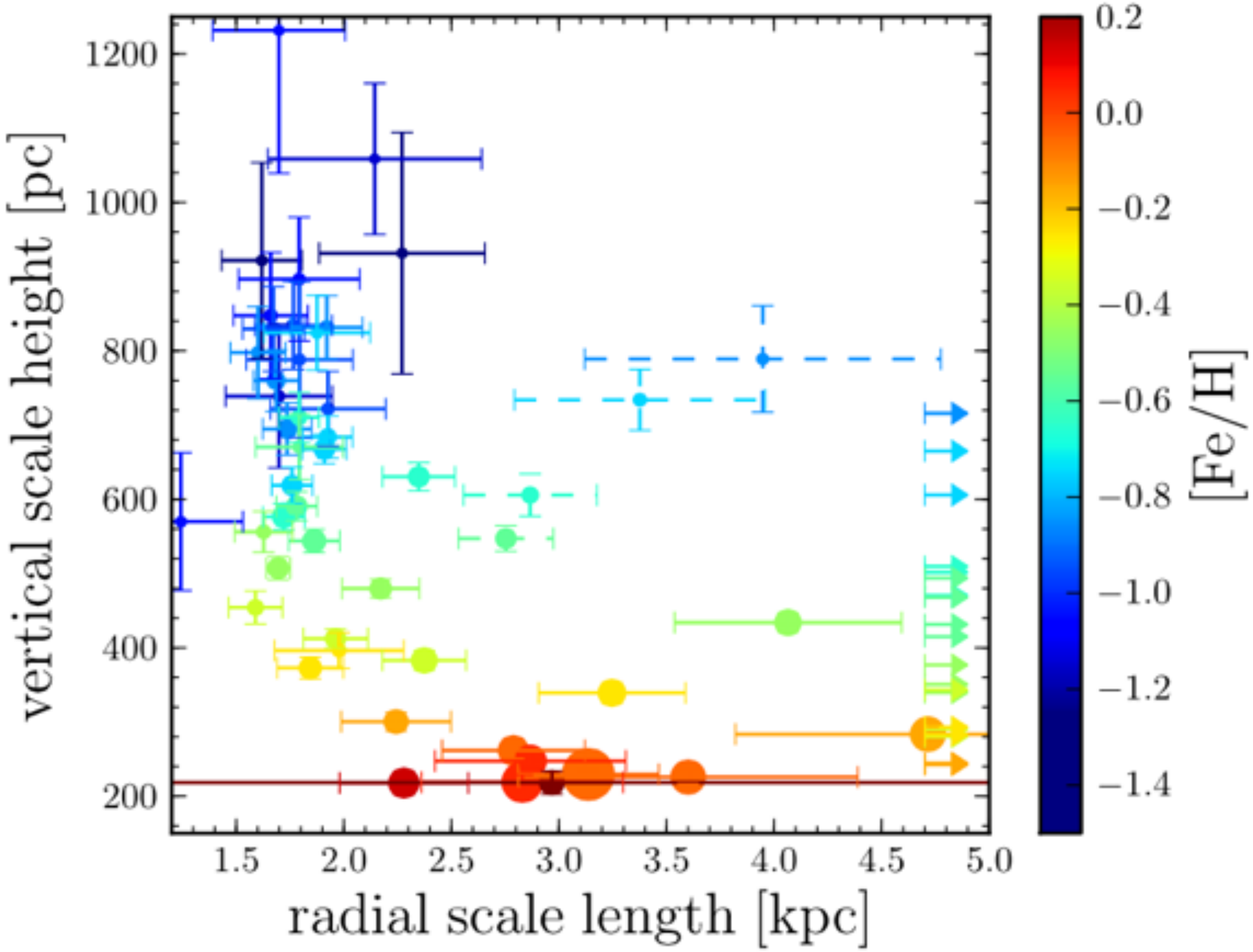


Figure 10. Scale-height as a function of scale-length for mono-age populations in the 7 simulated galaxies. The scale-heights are measured at a radius of $2R_d$. The colourcode and panel order are the same as in Figure 5. We find that the observed anti-correlation between scale-height and scale-length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

Martig, Minchev & Flynn, 2014



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

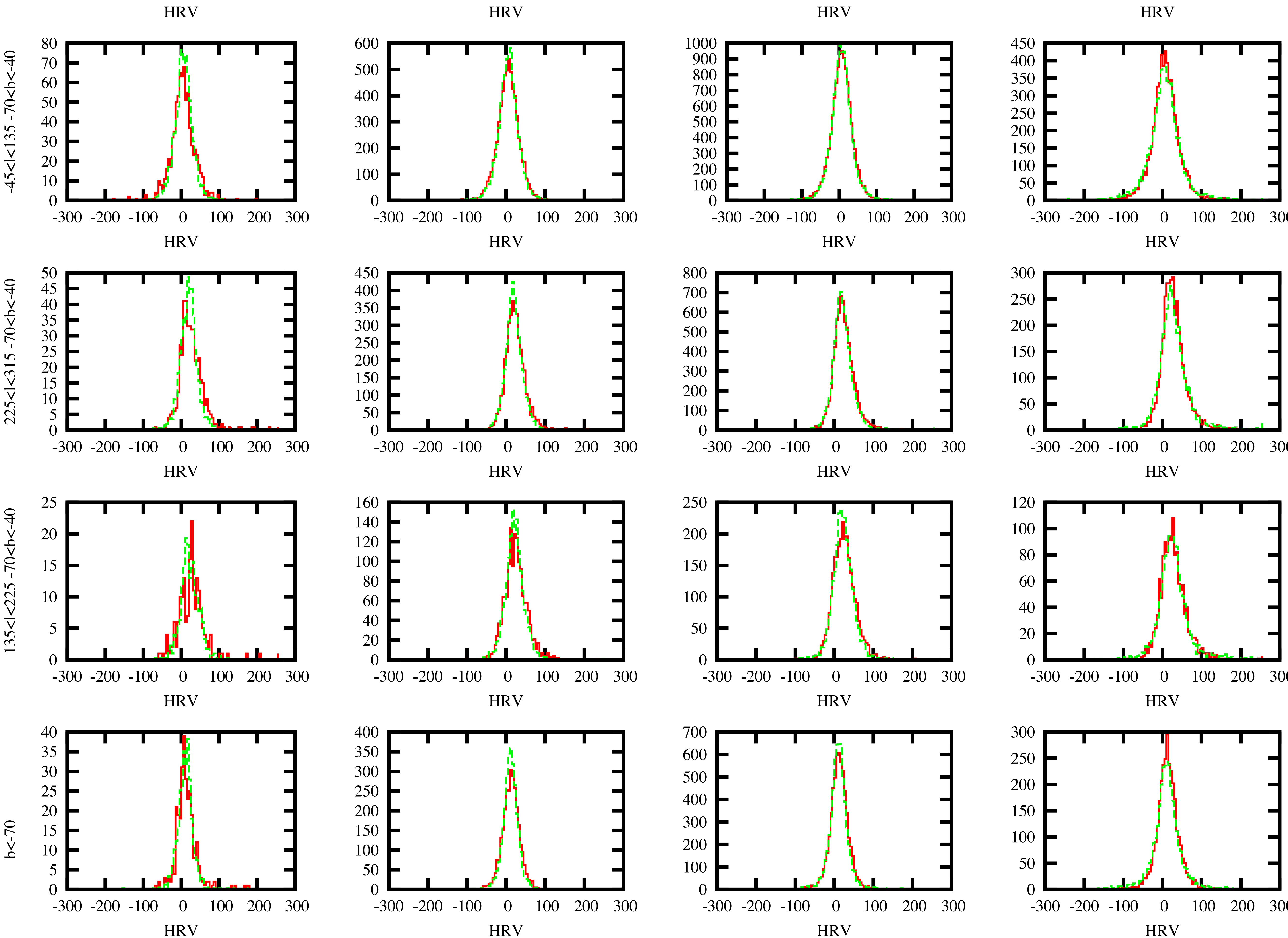
RAVE survey

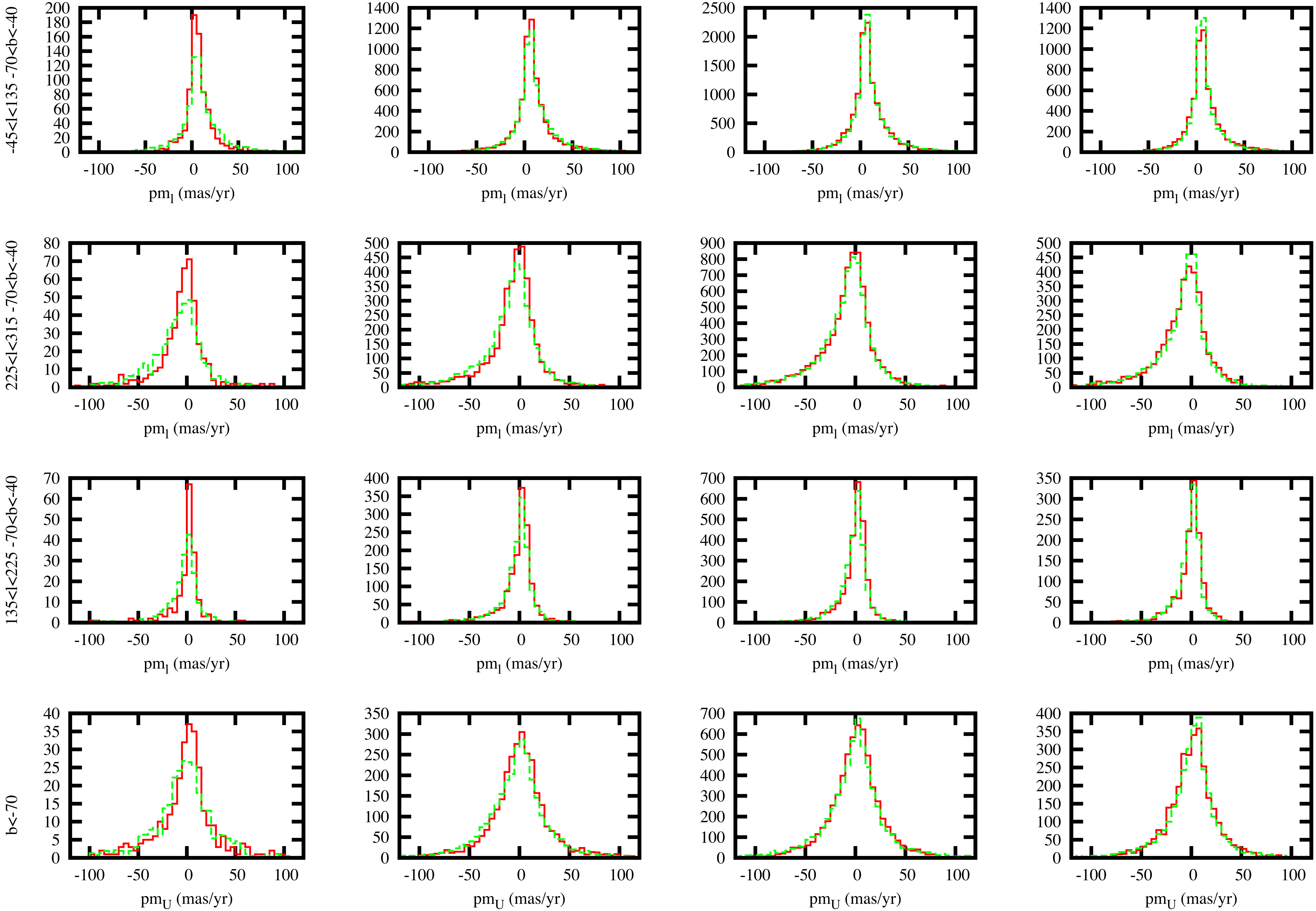
- Simulating the RAVE selection function
- $|b| > 20°$ to avoid extinction problems
- Fit kinematic model for the thin and thick disc (ABC-MCMC)

Fitted parameters

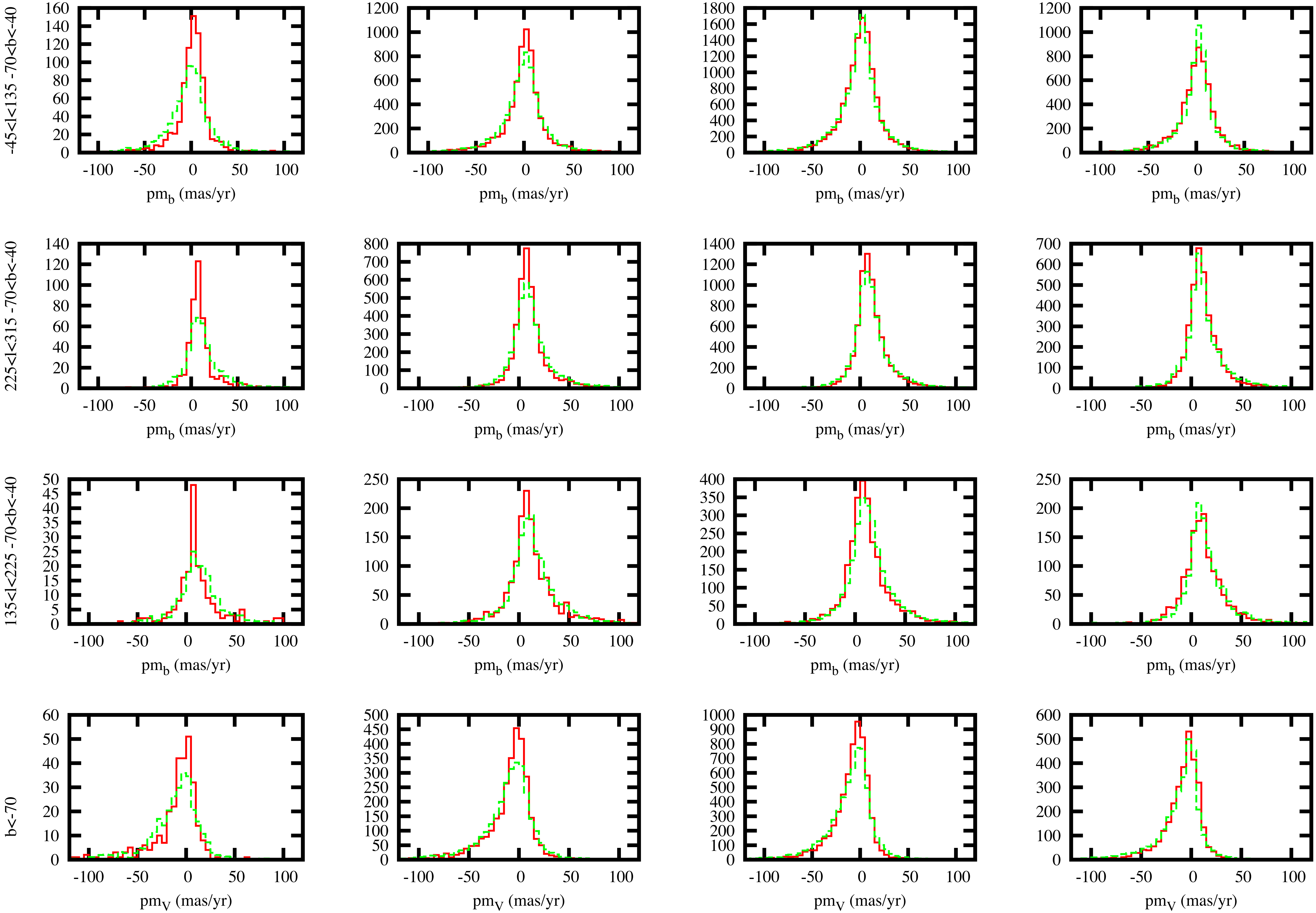
- Solar motion
- Circular velocity of the thick disc phases, velocity dispersions
- Thin disc velocity dispersion :
  - $\sigma_W = \sqrt{(a * \tau + b)}$
- Correct computation of the asymmetric drift out of the plane (O. Bienaymé)

	U	**V**	**W**
Sun velocities	8.7 ±1.	8.4±1	6.4±1
Velocity dispersions Thick disc 10 Gyr	35±4	25±4	25±4
Thick disc 12 Gyr	68±10	48±9	48±9


HRV
-45<l<135 -70<b<-40
225<l<315 -70<b<-40
135<l<225 -70<b<-40
b<-70
-300 -200 -100 0 100 200 300



-45<l<135 -70<b<-40
225<l<315 -70<b<-40
135<l<225 -70<b<-40
b<-70
pm_l (mas/yr)
pm_U (mas/yr)


-45<l<135 -70<b<-40
225<l<315 -70<b<-40
135<l<225 -70<b<-40
b<-70
pm_b (mas/yr)
pm_V (mas/yr)

Thick disc circular velocities

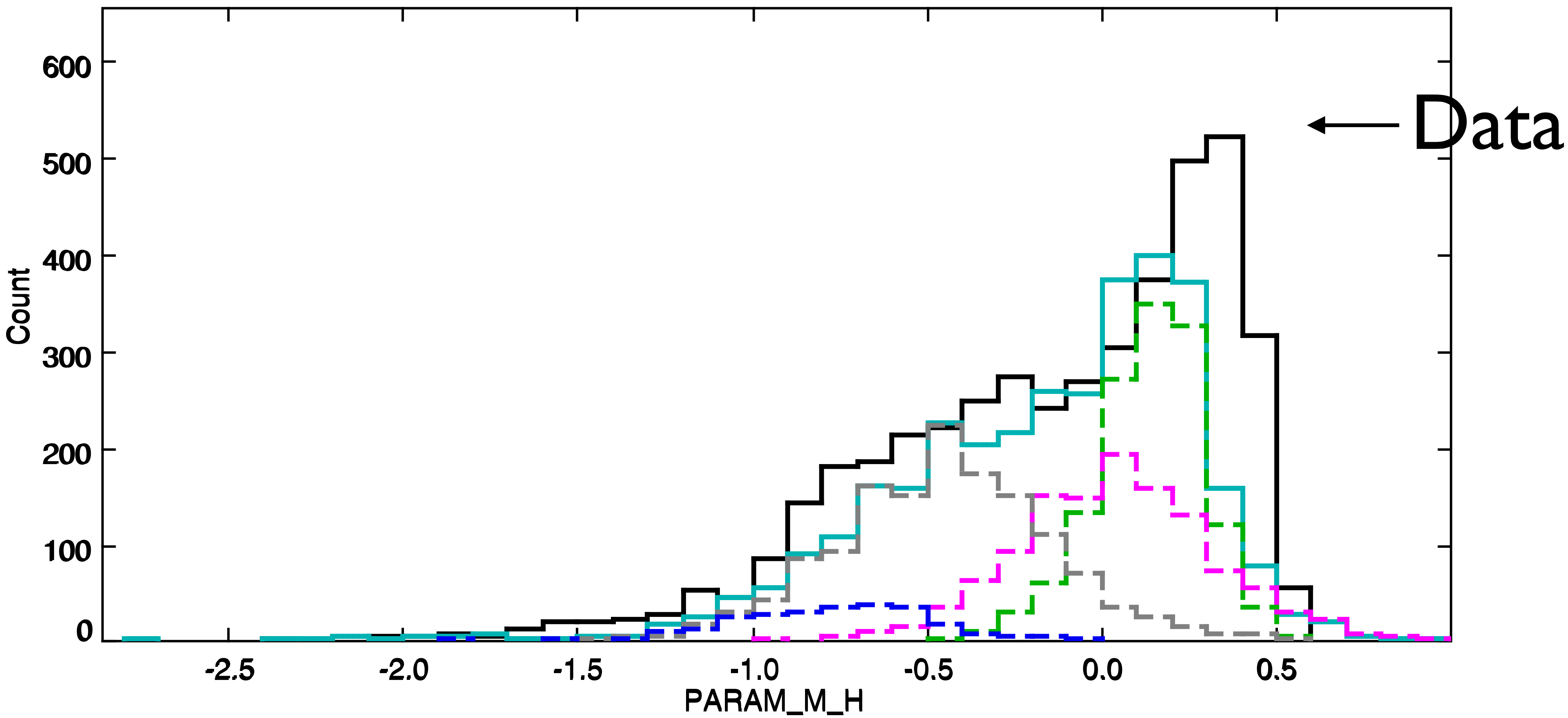
12 Gyr : 175±9 km/s
10 Gyr : 207±4 km/s

- *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*

APOGEE

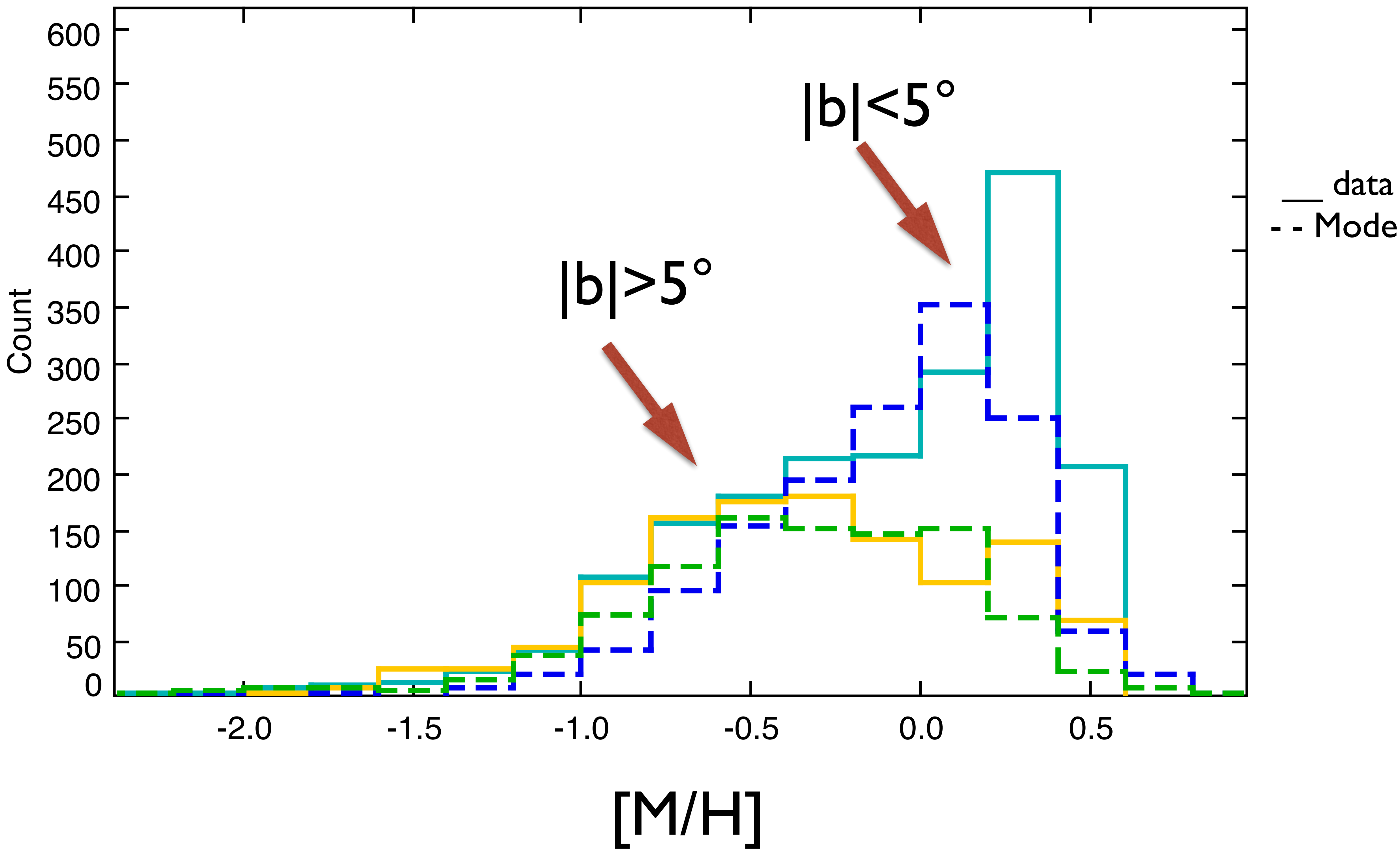
- Preliminary application of the target selection in the bulge region
- Test for the new model of thin and thick disc.

Bulge fields : 0°<l<18°, -14°<b<14°



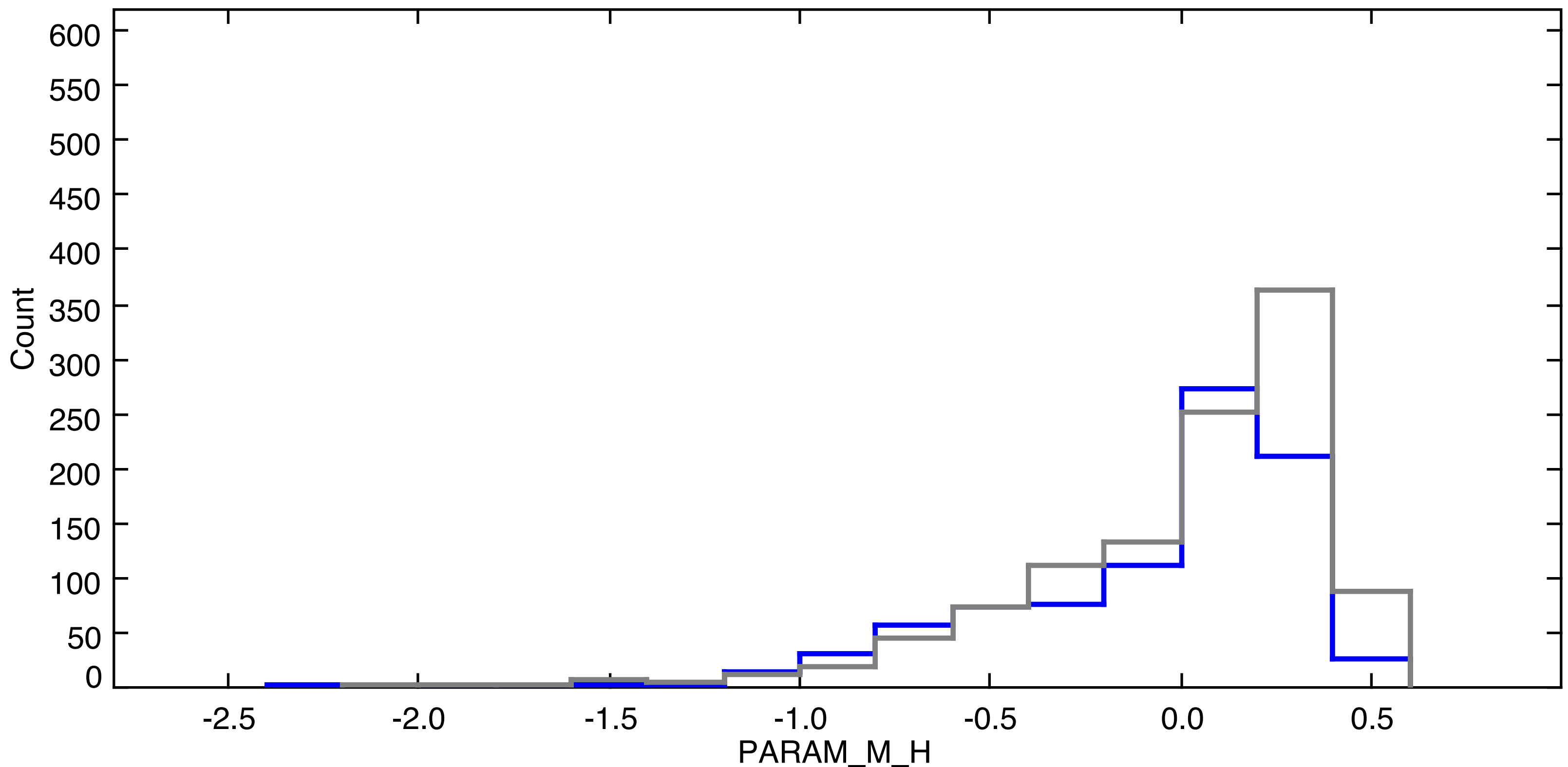
[M/H]

Inner bulge $l<10°$



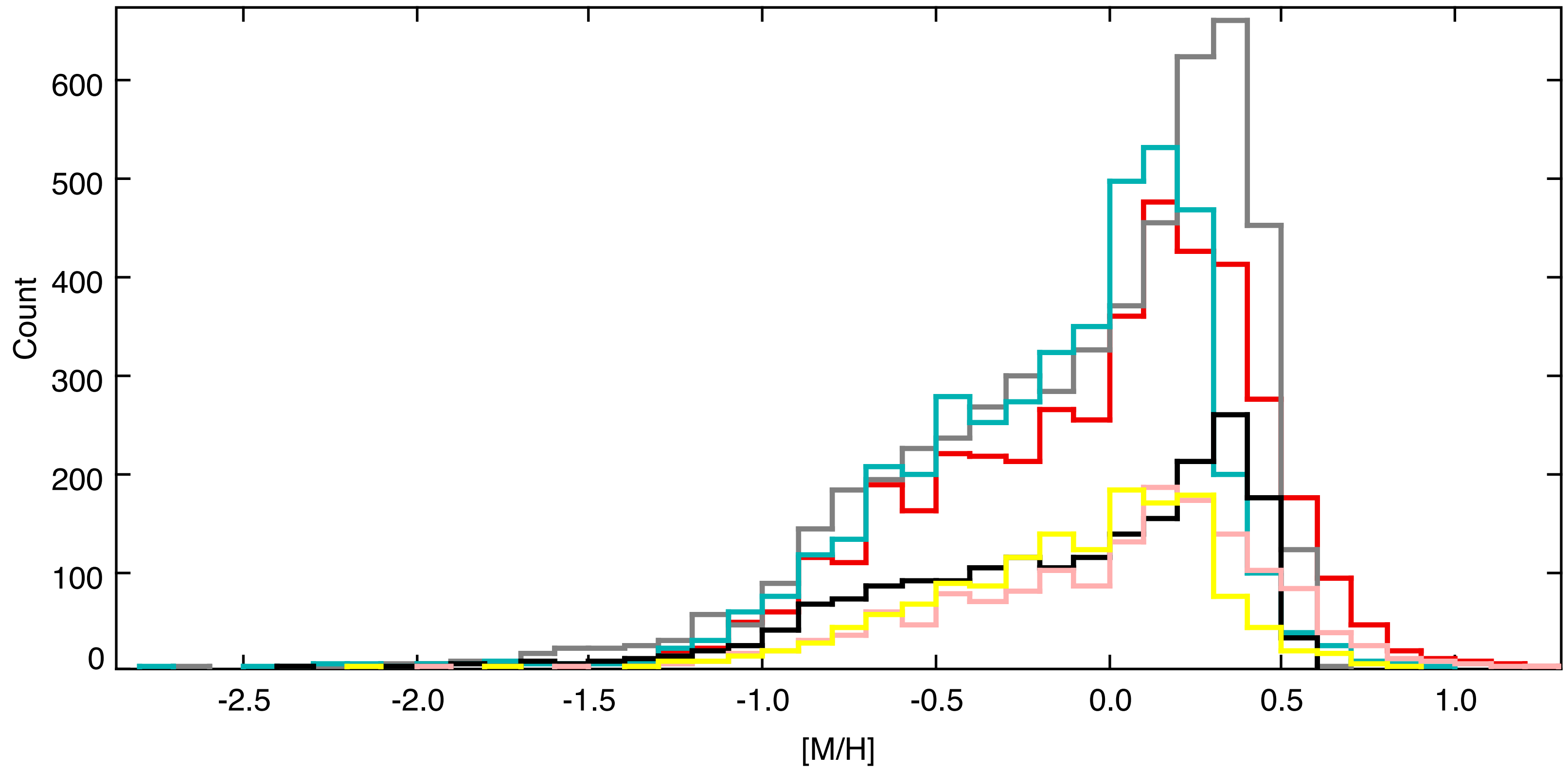
Lower latitudes dominated by the bar and thin disc: high [M/H]
Higher latitudes dominated by the thick disc: low [M/H]

10°<l<20°

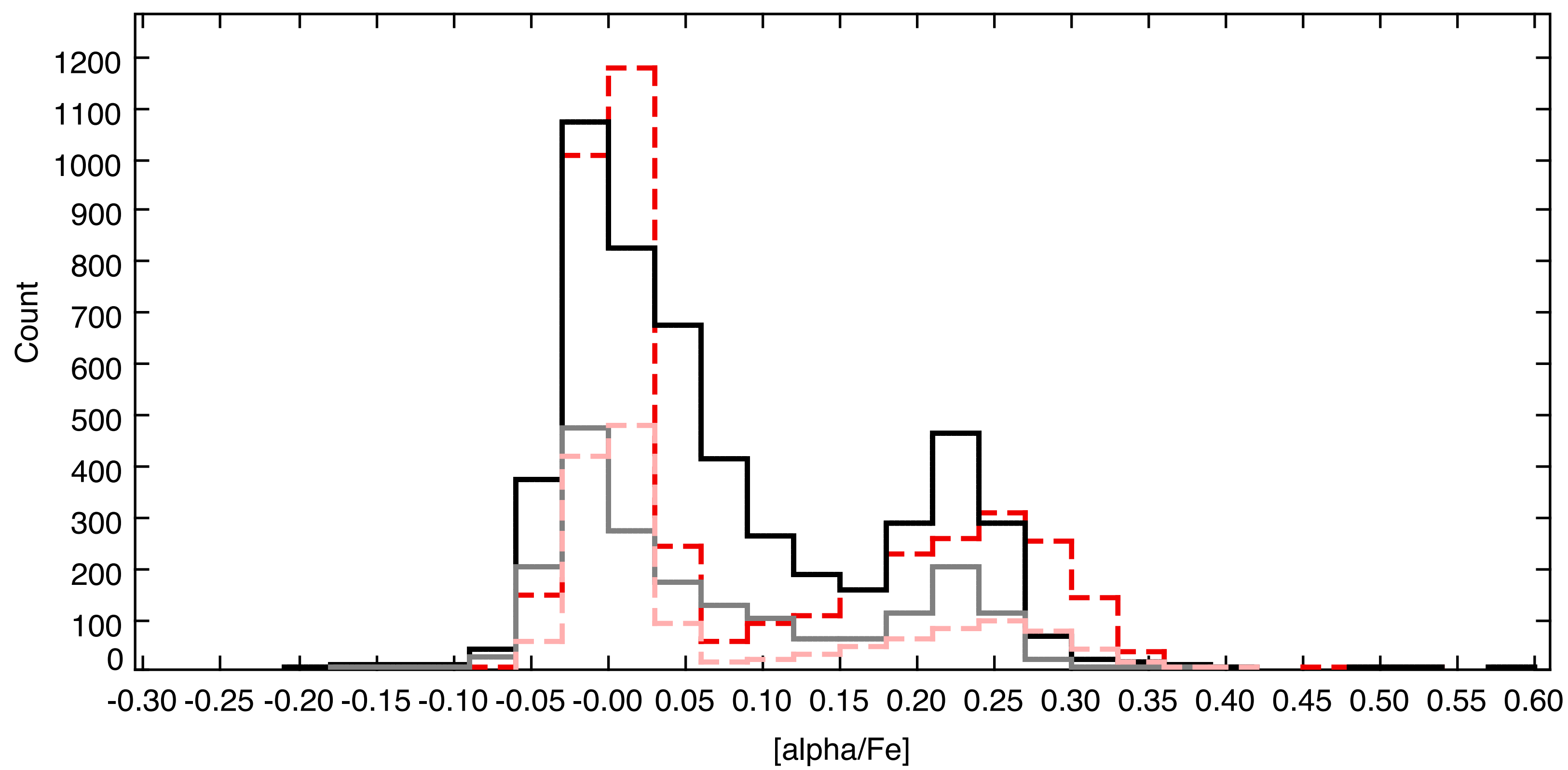


[M/H]

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



_Data all bulge
_l<10° |b|<5°

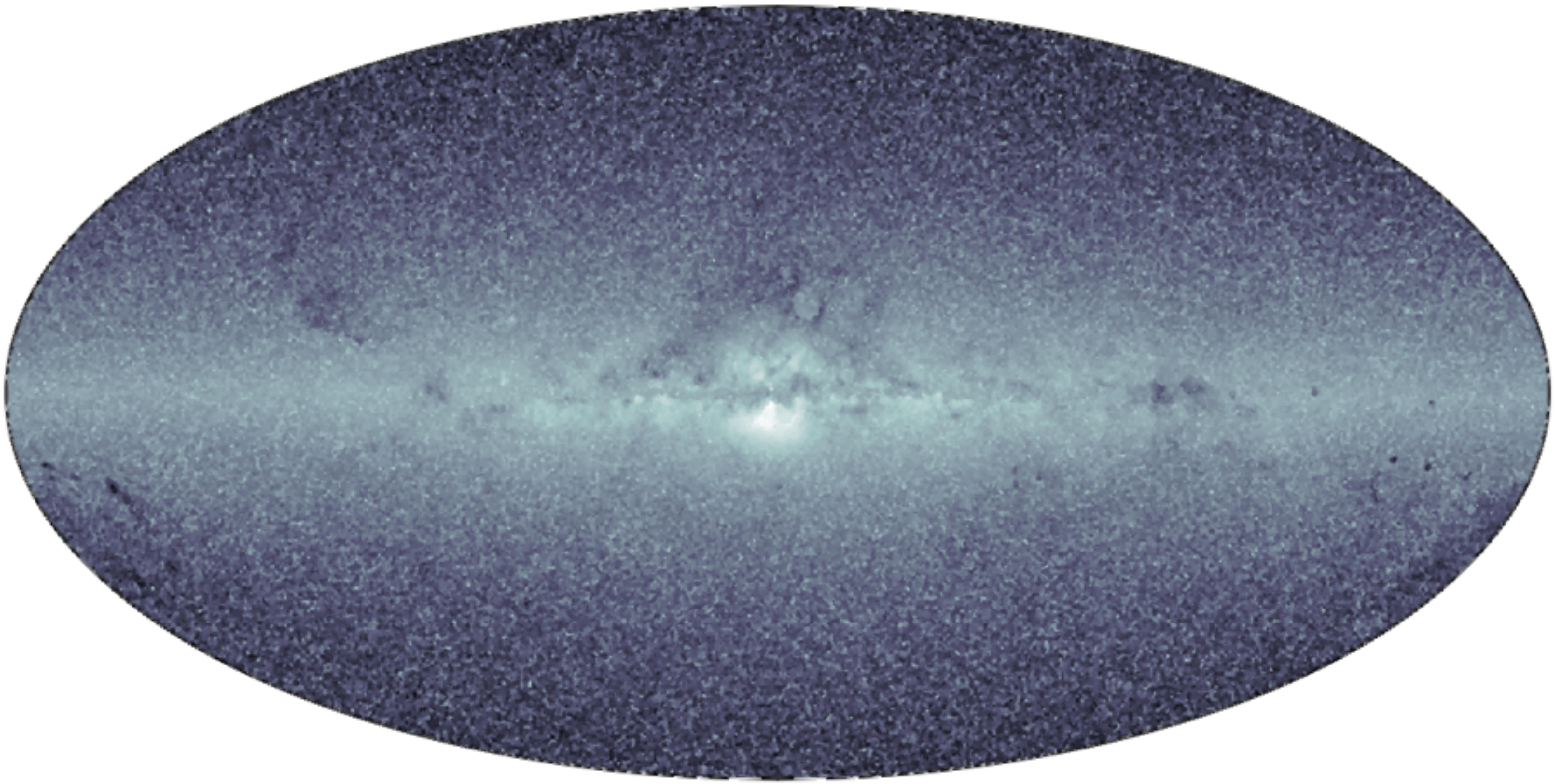
- - Model
- - -l<10° |b|<5°

[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

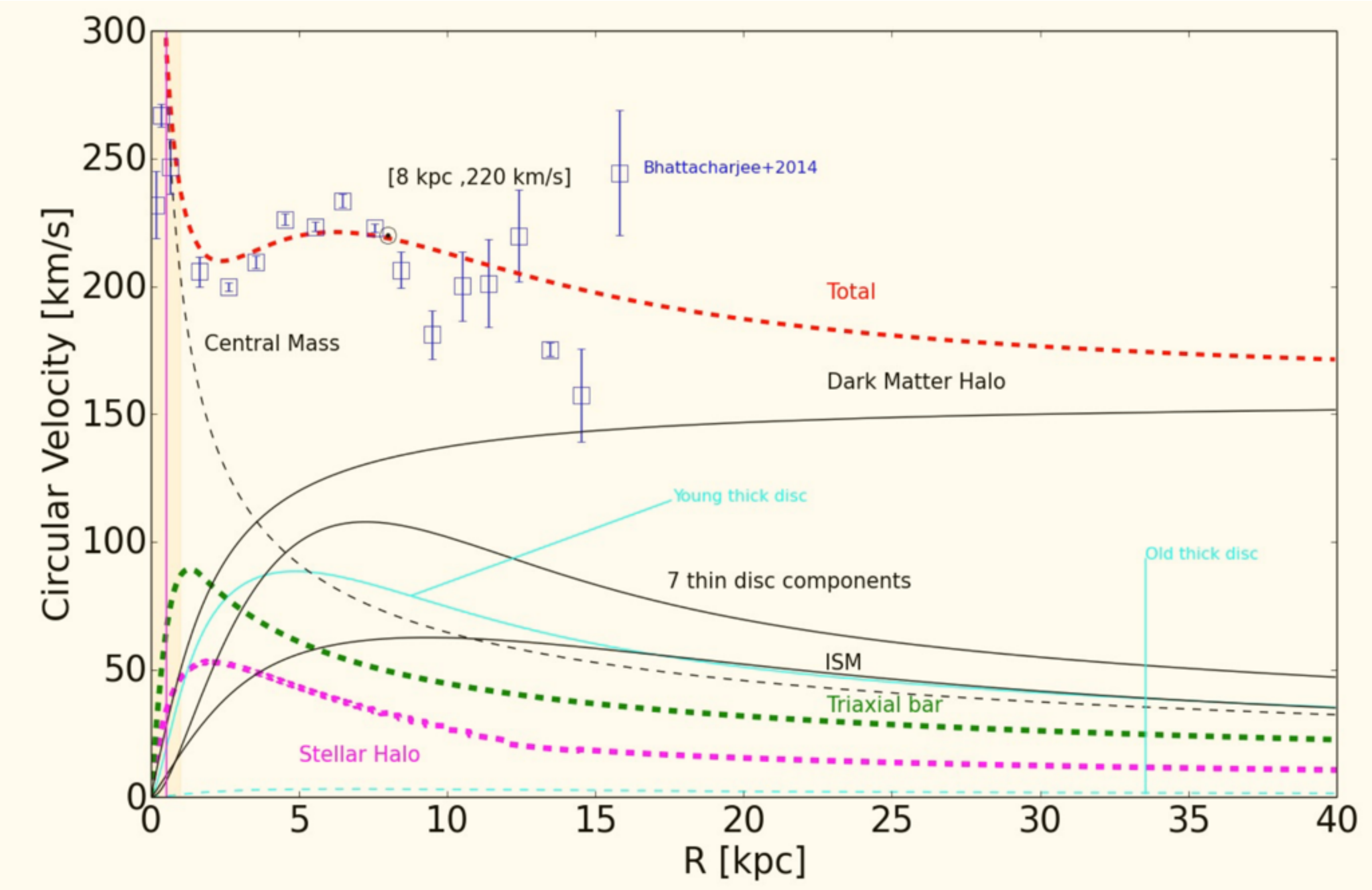
- The thick disc formed during a long episod of formation, gas turbulence supported but slightly contracting
- The thin disc formed inside out
- The new Thin disc/Thick disc model reproduces well the distributions seen in RAVE and APOGEE
- Explain the complex MDF in the bulge region by combination of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



300
250
200
150
100
50
0
Circular Velocity [km/s]
0
5
10
15
20
25
30
35
40
R [kpc]
[8 kpc ,220 km/s]
Bhattacharjee+2014
Total
Central Mass
Dark Matter Halo
Young thick disc
Old thick disc
7 thin disc components
ISM
Triaxial bar
Stellar Halo