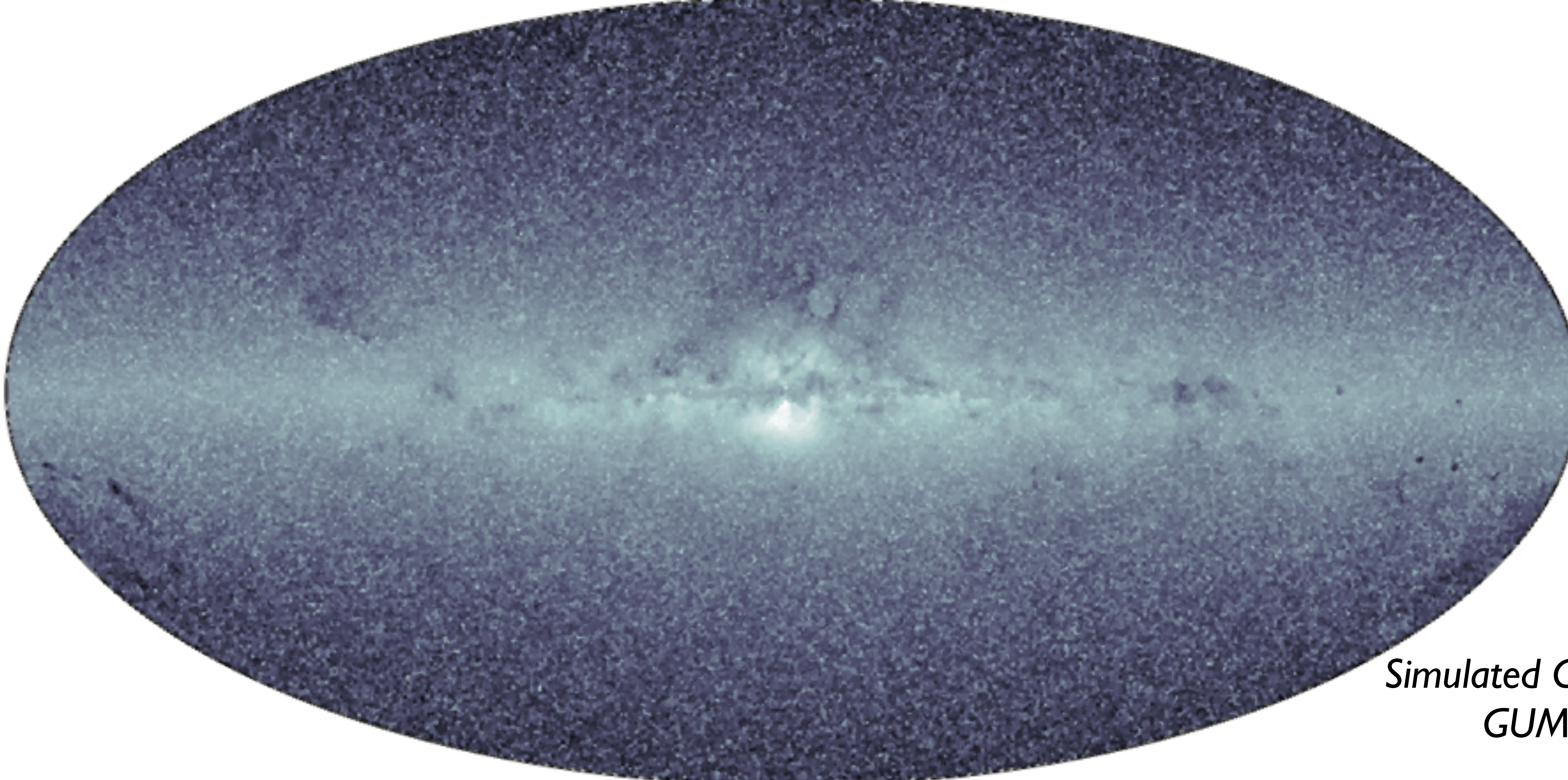

Simulated Gaia sky
GUMS

Population synthesis modelling : Statistical analysis of large scale survey data to constraint the Galactic disc evolution

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Outline

- Why modelling the Milky Way ?
- Constraining model parameters / scenarios : efficient 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,
- Gaia perspectives

Preambule

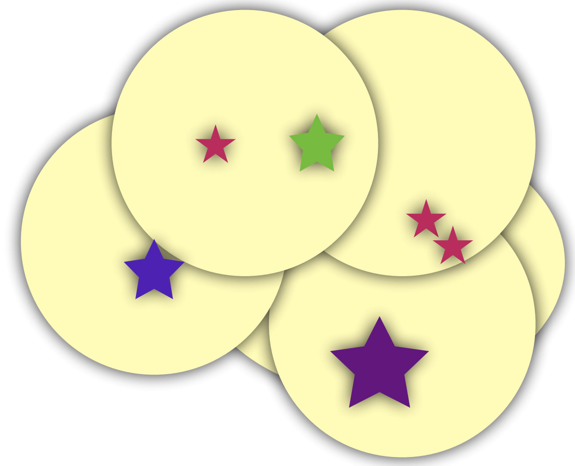
- Galactic archeology much more difficult than distance cosmology: you have distances and ages 😉
- How can we do Galactic archeology without **good** *distances* and *ages* ?
- The Gold Age : Gaia, spectroscopic surveys, Corot-Kepler-PLATO

Introduction

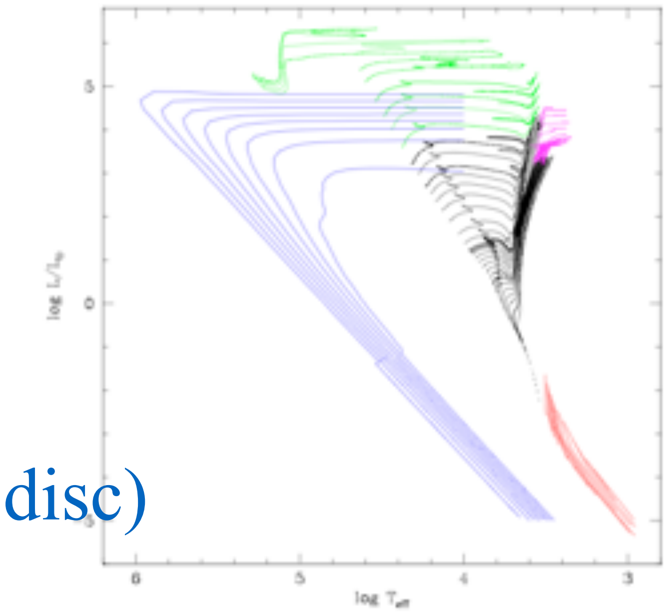
- Surveys : photometric, spectroscopic, multi-wavelength

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

Population synthesis



Start with a mass of gas
=> Transform into stars as functions of IMF and SFR



Stars evolve on evolutionary tracks
and populate the HR diagram

Proceed for the age of the population (~10 Gyr for the thin disc)

=> φ(Mv, Teff, log g, age)

Important ingredients : SFR, IMF, stellar models, atmospheres

Population synthesis

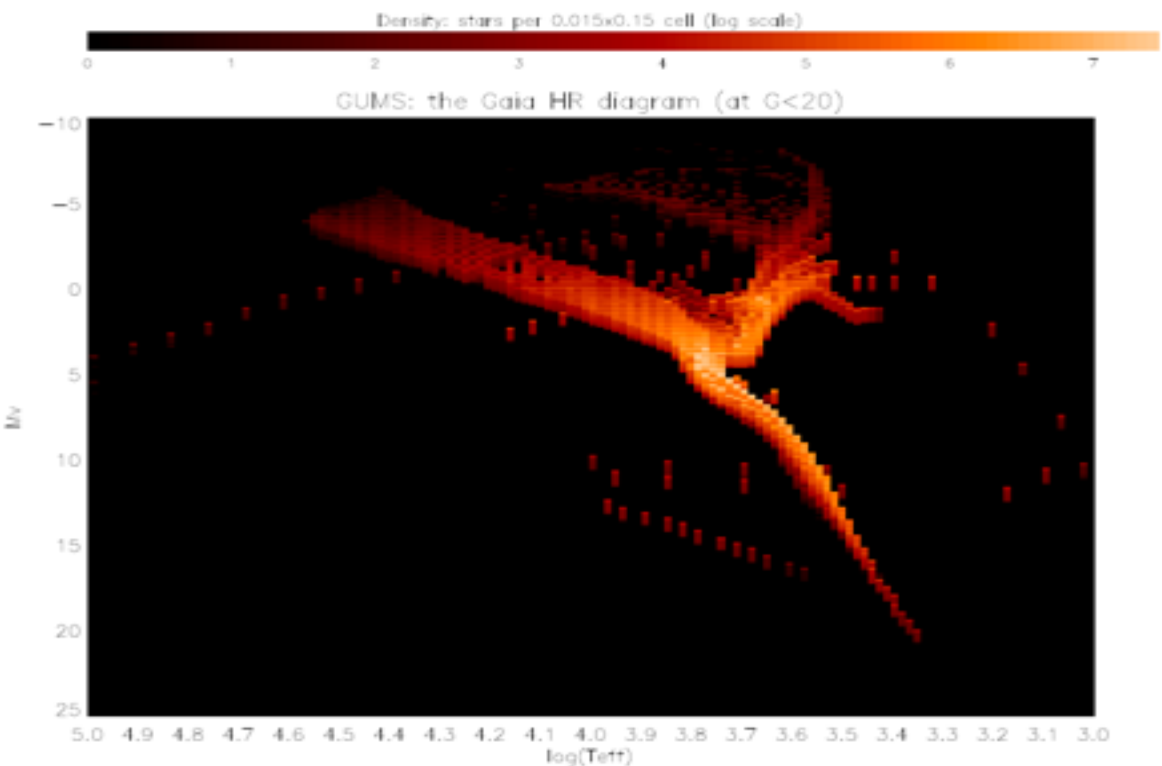
Simulations of surveys

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

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

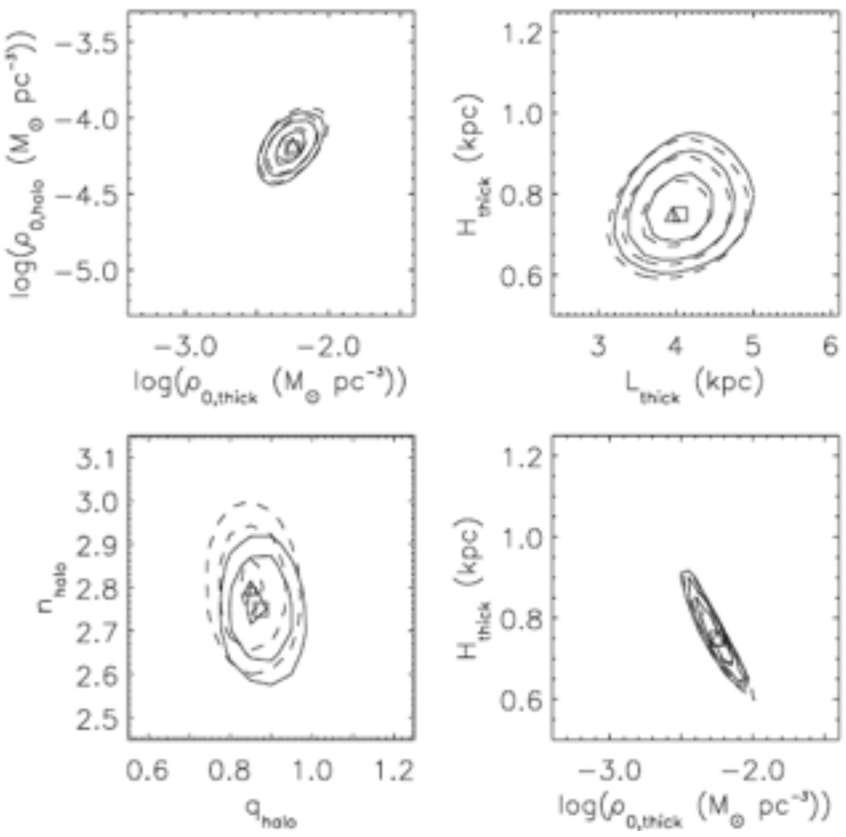
Simulate observational errors

Population Synthesis Modelling

- Start with a scenario of formation and evolution for the Galaxy
- Population synthesis approach: many parameters but **more understanding :** Link between **scenarios** and **observations**
- **Increasing** complexity (start simple…)
- **Statistical treatment** : **Large surveys** provide the way to combine many observables and stay statistically significant (abundances/kinematics/position)
- Model c**onfronted to many observables** : magnitudes, colours (many bands), proper motions, radial velocities, Teff, logg, [Fe/H],[alpha/Fe], even astero-seismic parameters in the future
- Try to have a self-consistent solution to the puzzle

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

Application

- Thin and thick disc formation
- Thick discs exist in many galaxies
- Scenarios of formation go from top-down to bottom-up, secular evolution (migration..) to mergers, separated from the thin disc to completely distinct history
- Tracers of thick disc population : kinematics: no, abundances: yes

Motivation

Lee et al
SEGUE

Adibekyan+ 2012
HARPS local sample

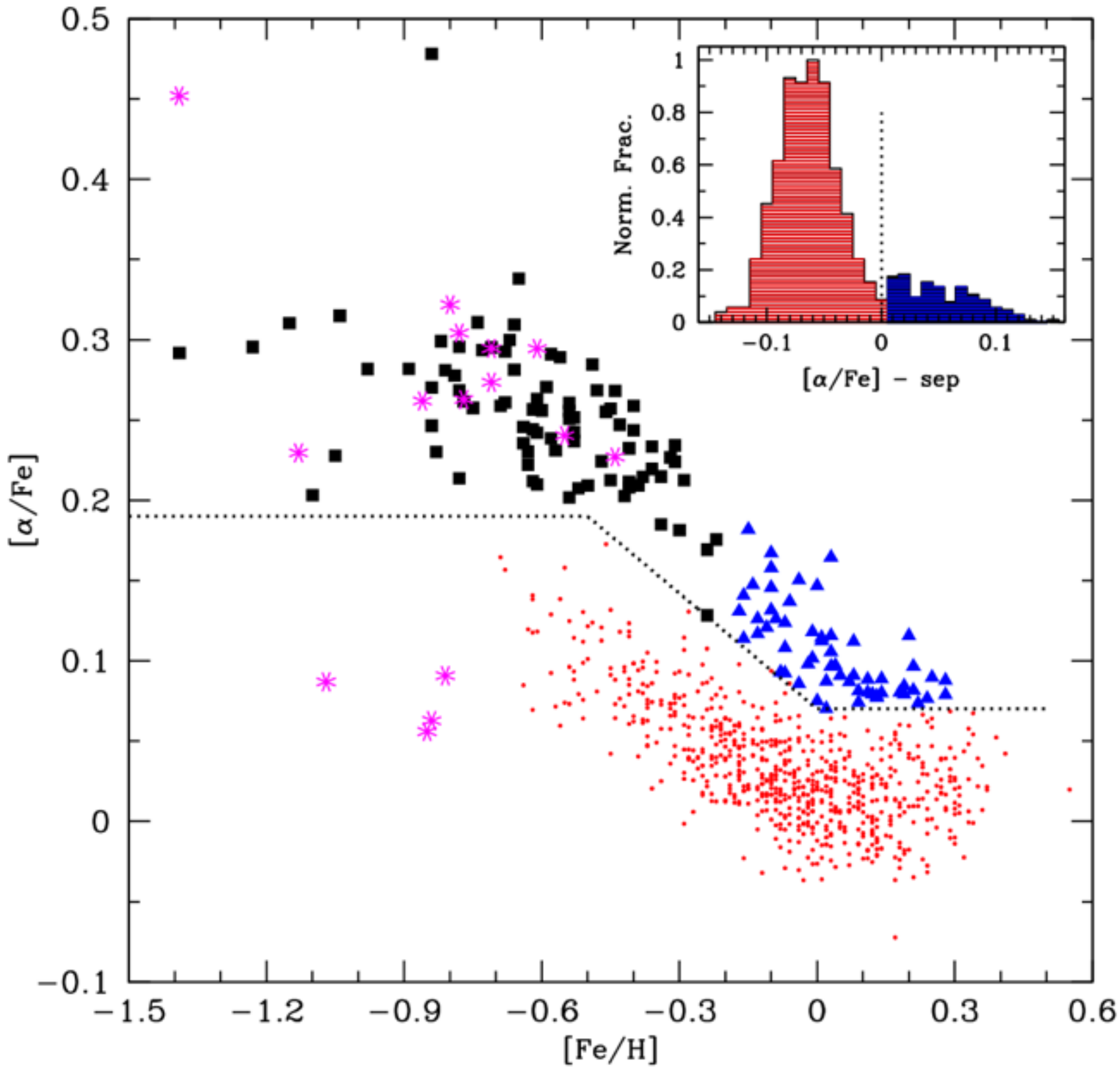
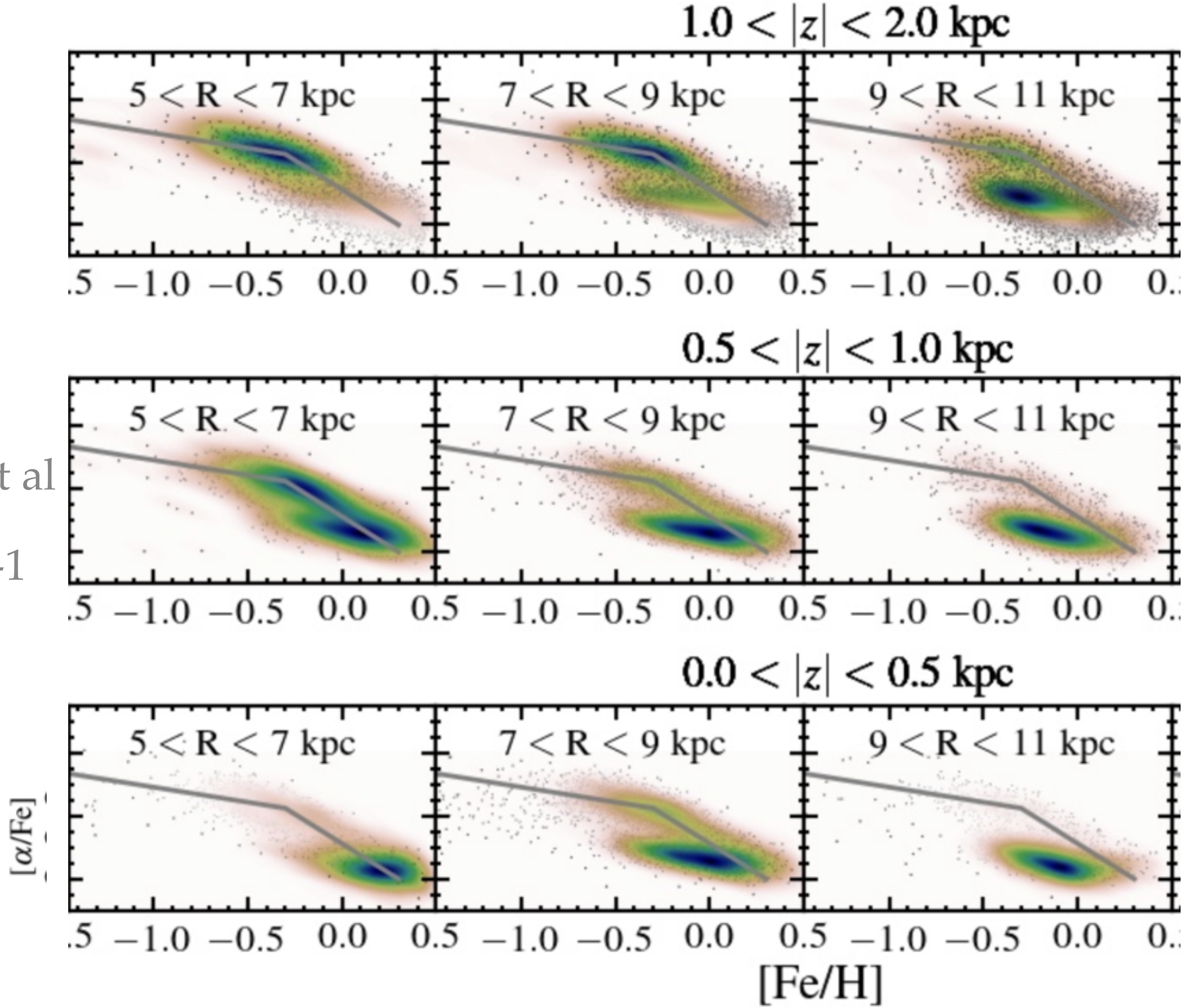


Fig. 1. [α/Fe] versus [Fe/H] for the whole sample. Magenta asterisks represent the stars belonging to the halo by their kinematics. The black

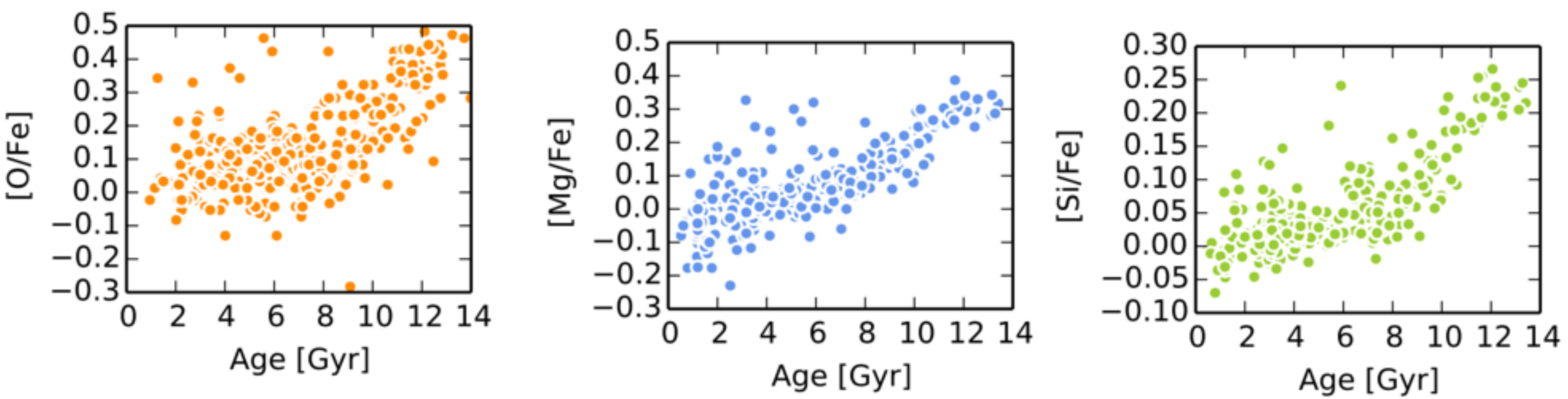
Hayden et al

APOGEE-1



Thick disc SFH

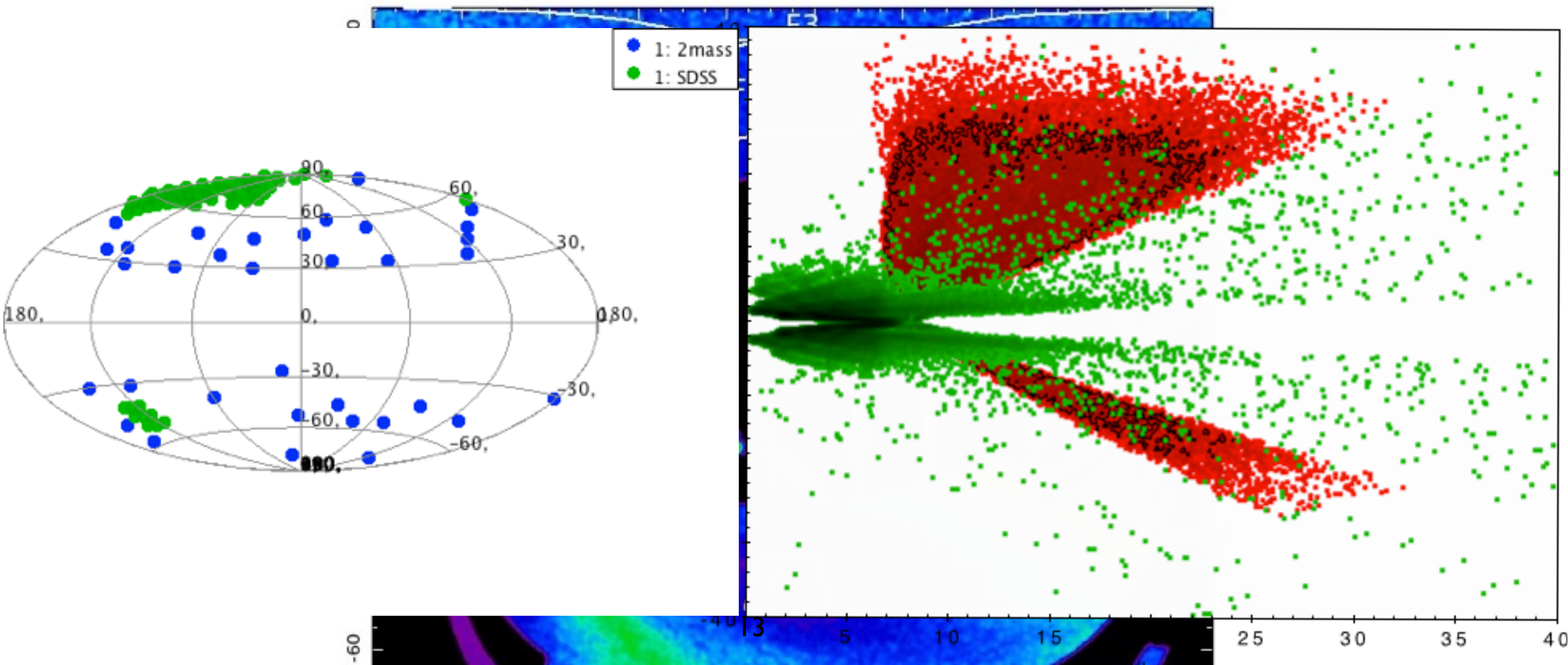
- Haywood et al, (2014), Snaith et al (2015) : long SFH in the thick disc phase



But spectroscopic samples are biased by their target selection. Difficult to quantify the spatial density distribution of the populations.

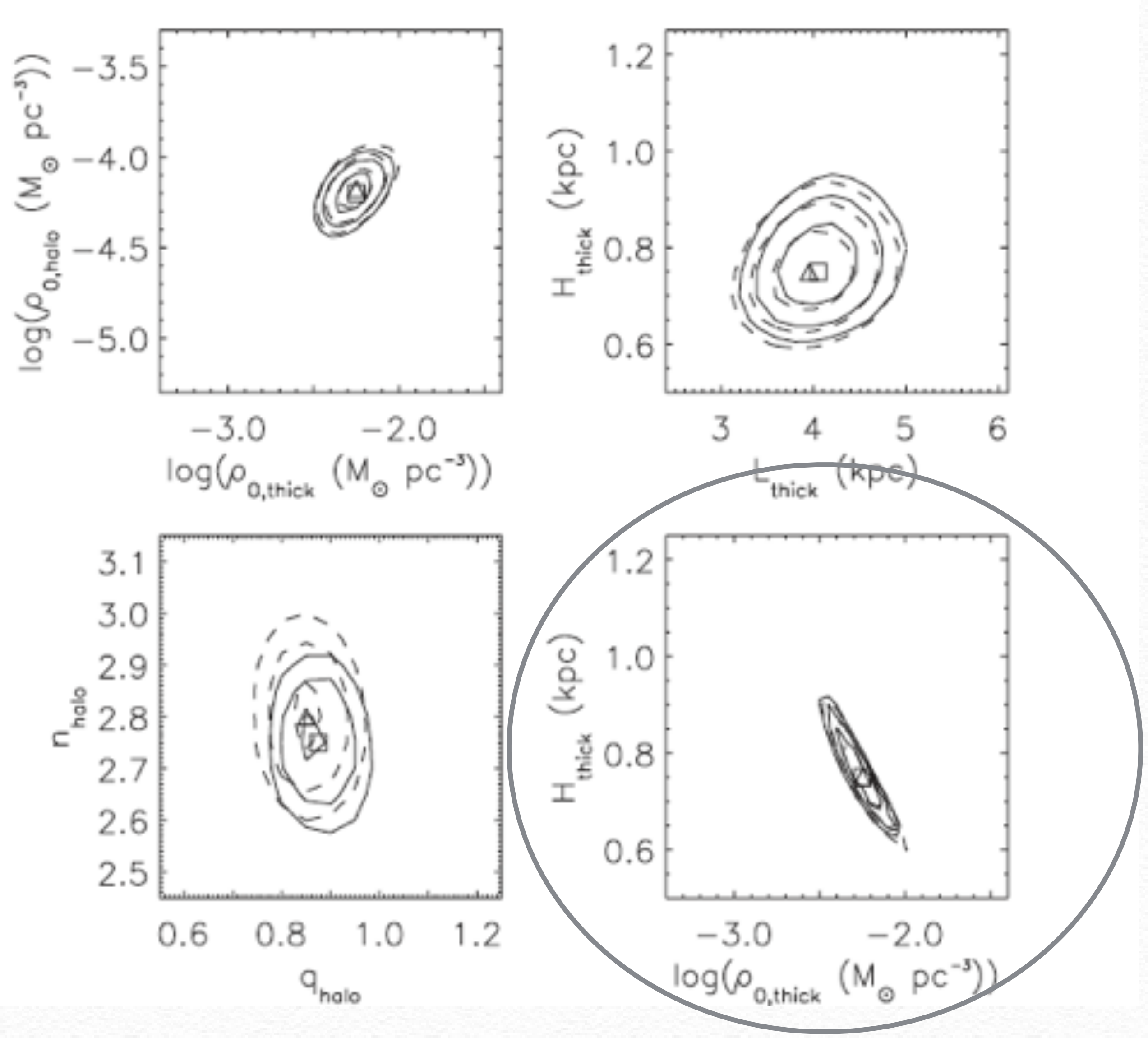
Thick disc and halo
From SDSS + 2MASS

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

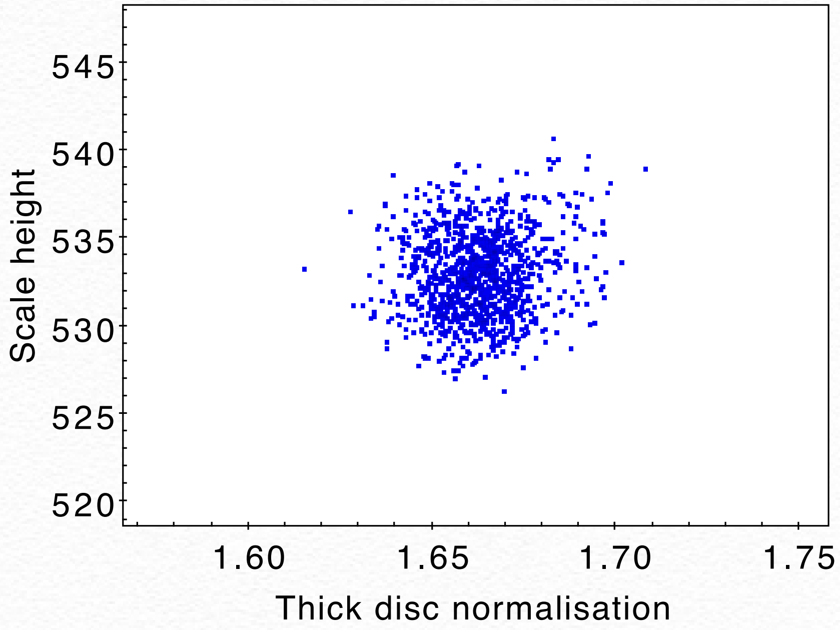


Get rid of degeneracies of thick disc scale height

Thanks to wide latitude range



De Jong et al, 2010



Also constraining the scale length and the flare

How long the thick disc formed stars

- Simulate the long formation history by 2 bursts (2 isochrones)
- Free parameters for each episode : scale height, length, normalisation, flare
- Assume different ages

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%

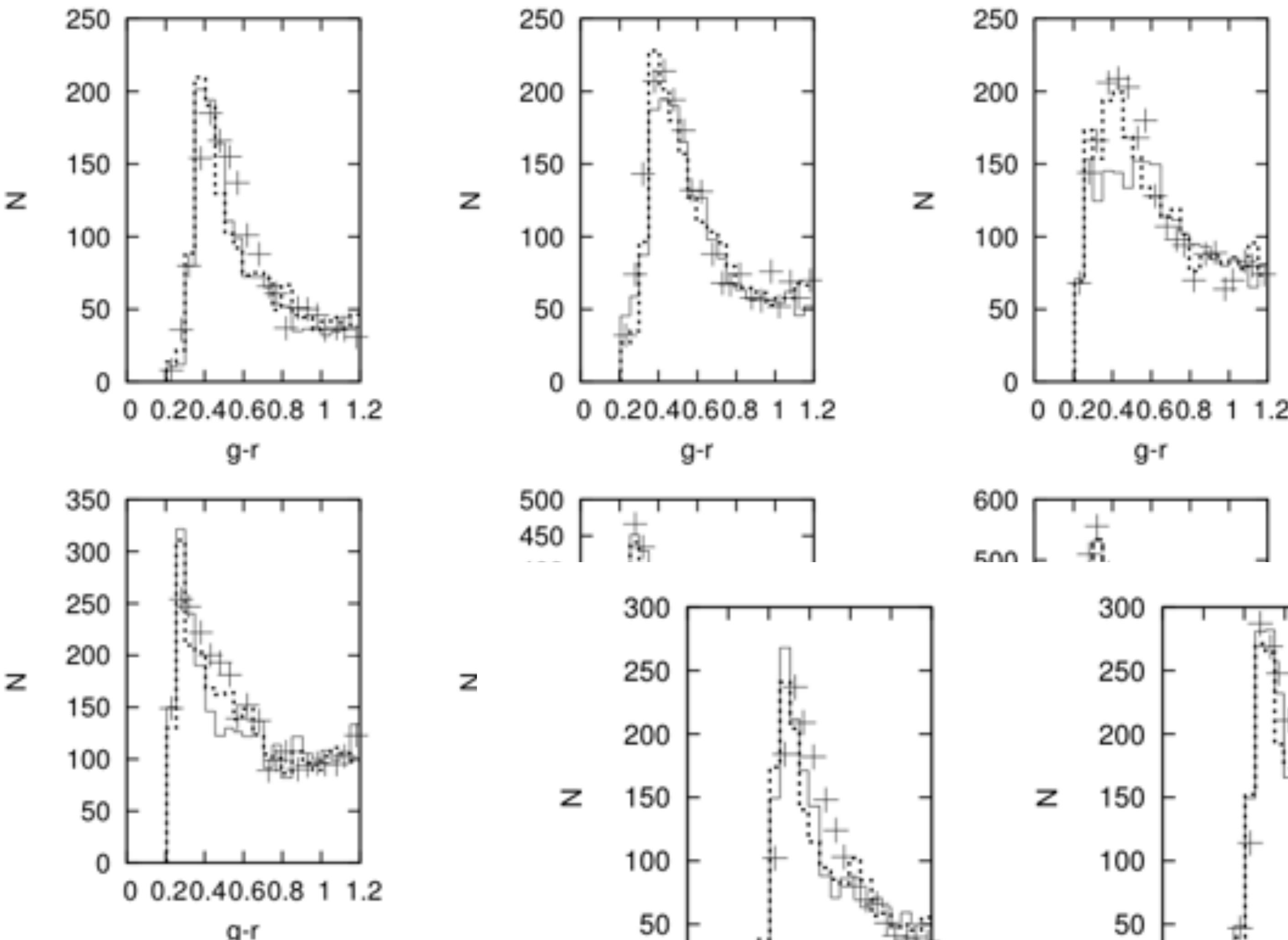


Fig. A.1. Comparison of the best fitne
for a different magnitude range, from
lines, model with two formation episod

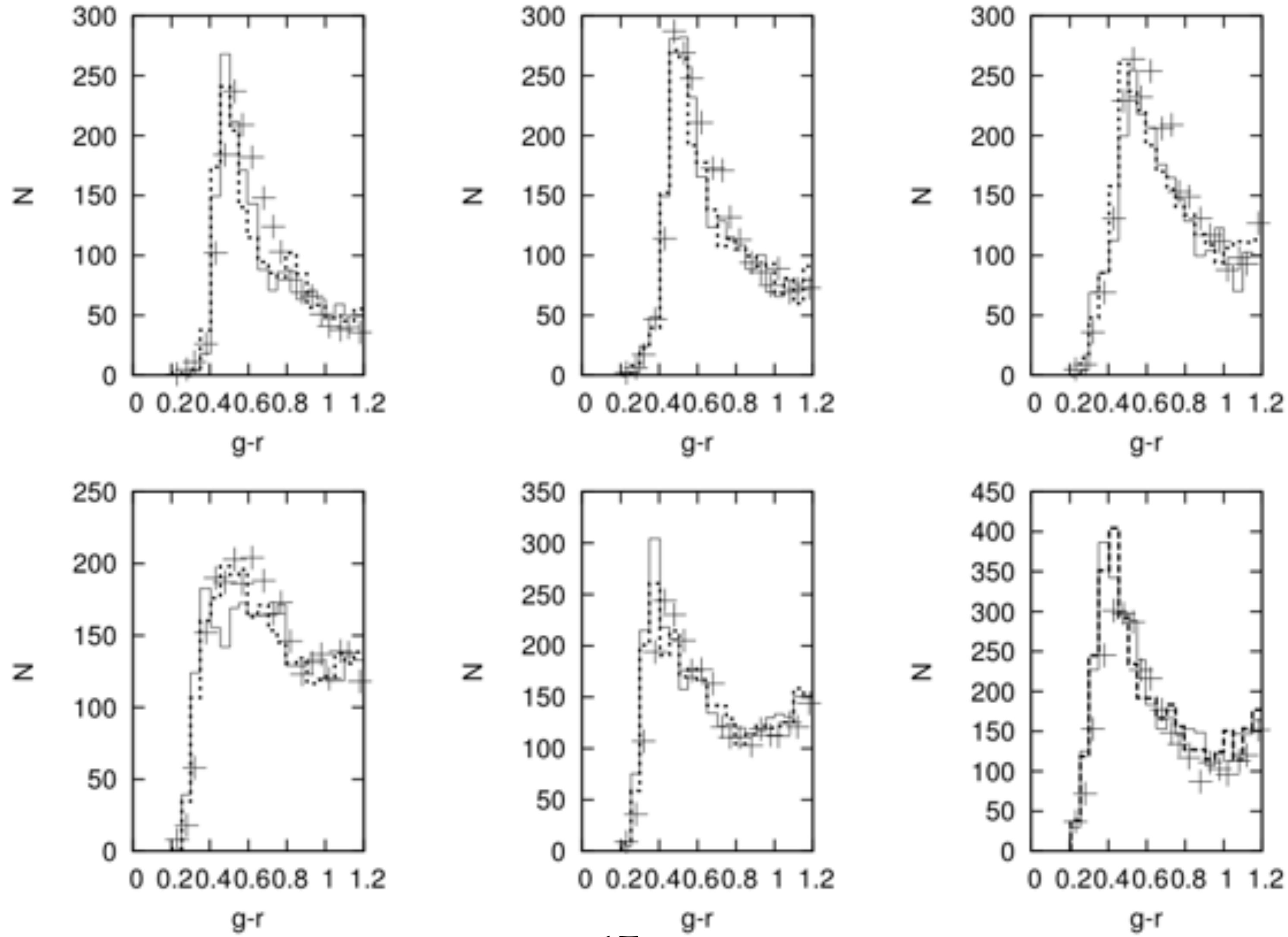
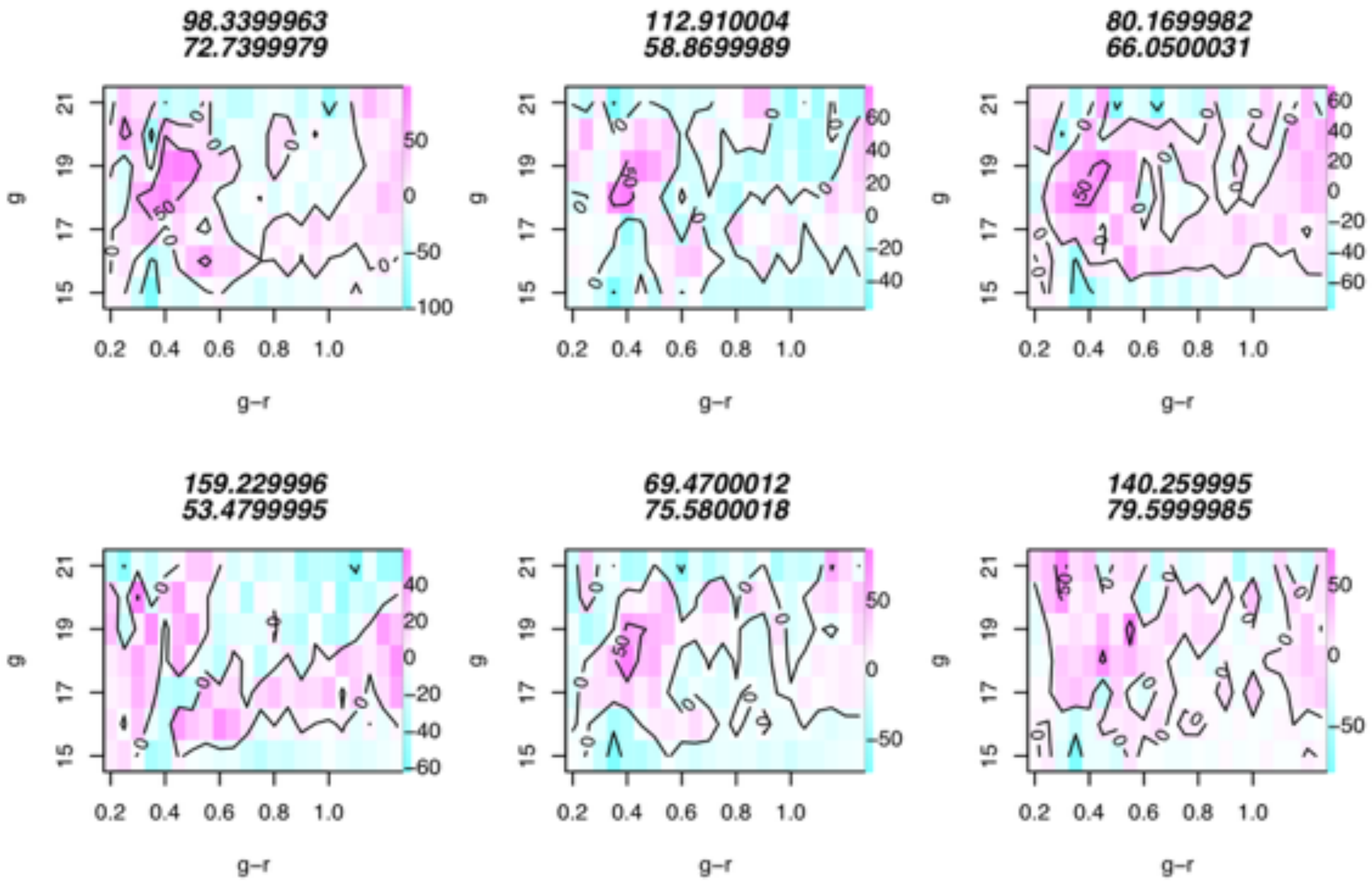


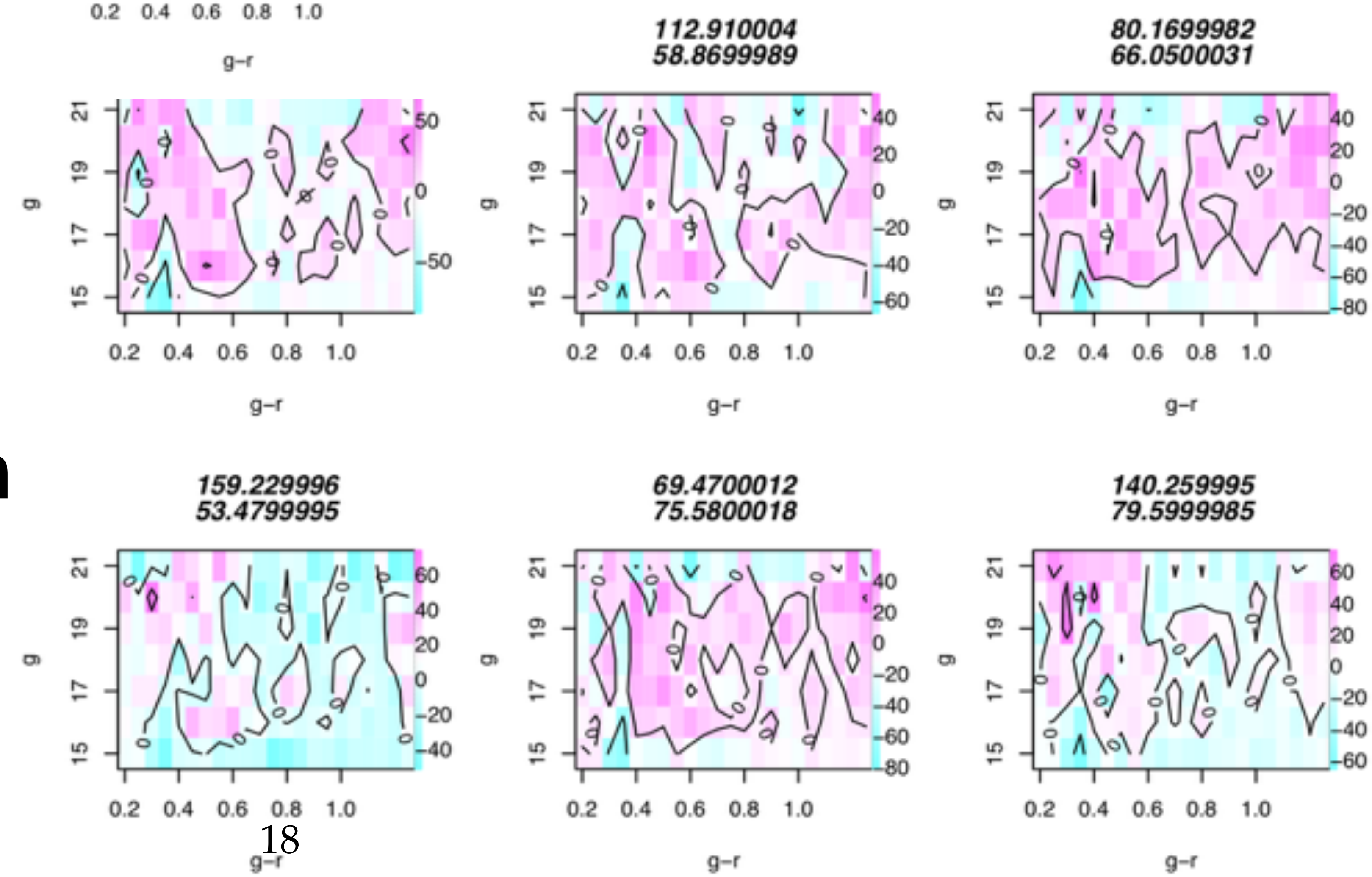
Fig. A.5. Same as figure A1 for SDSS field at longitude 116°, latitude -51°.

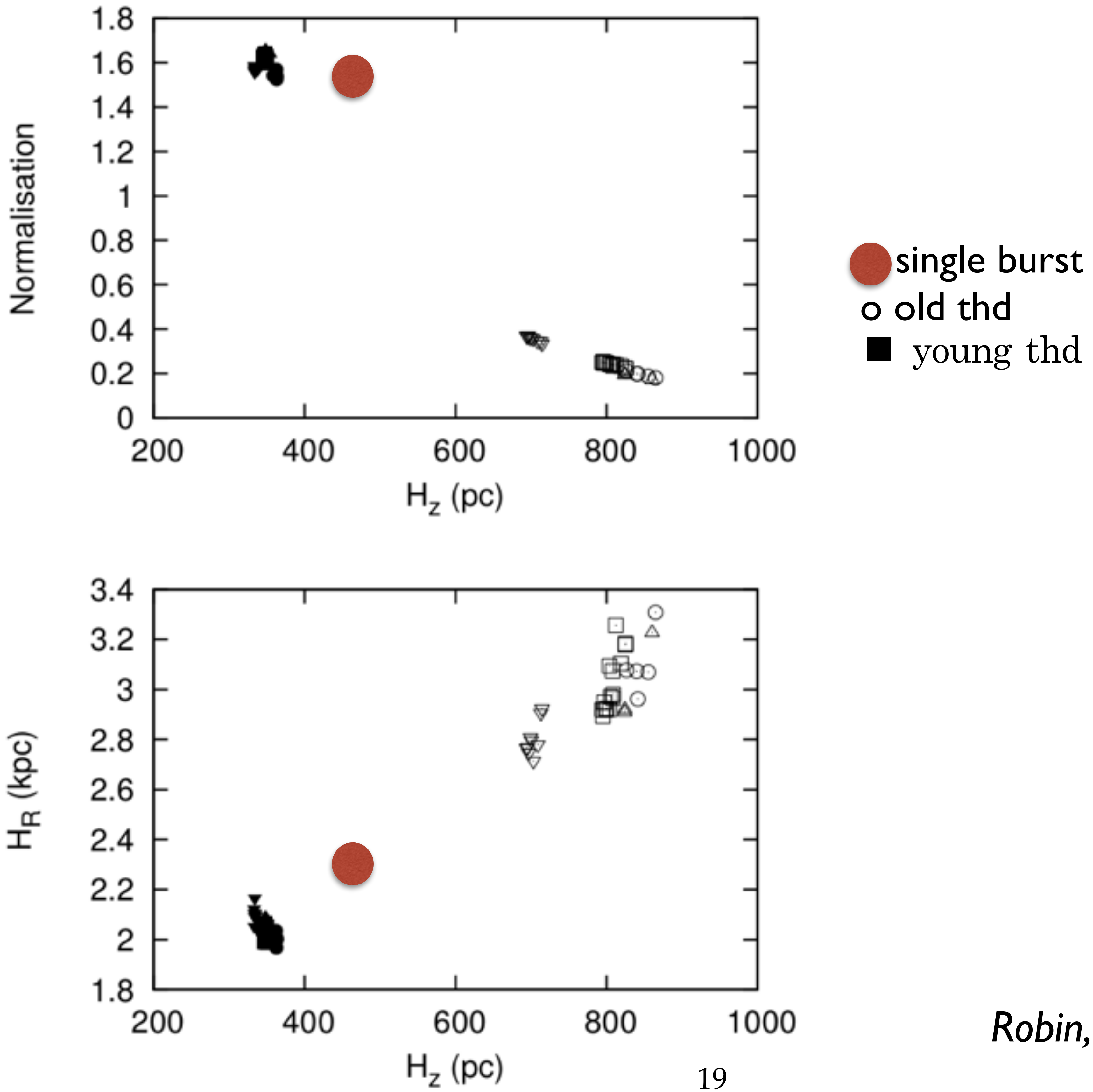
Residuals in CMDs

Single burst



Longer star formation





Robin, Reylé et al, 2014

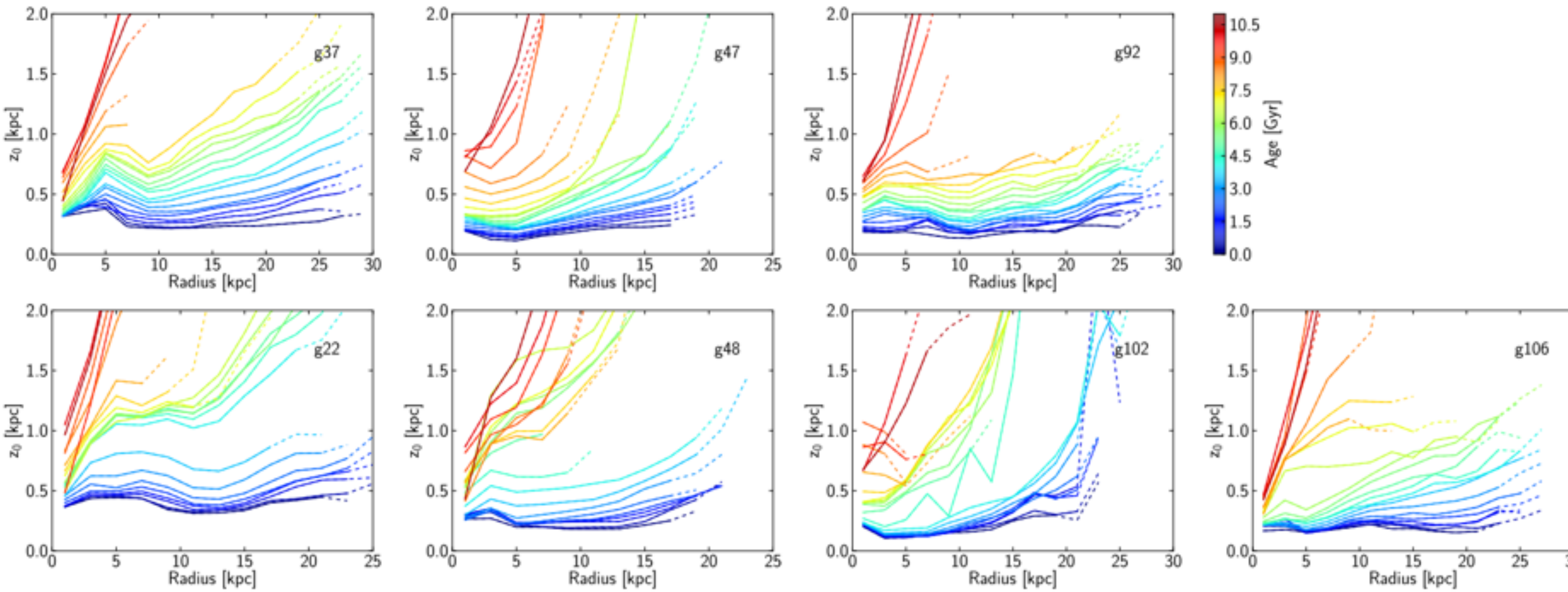
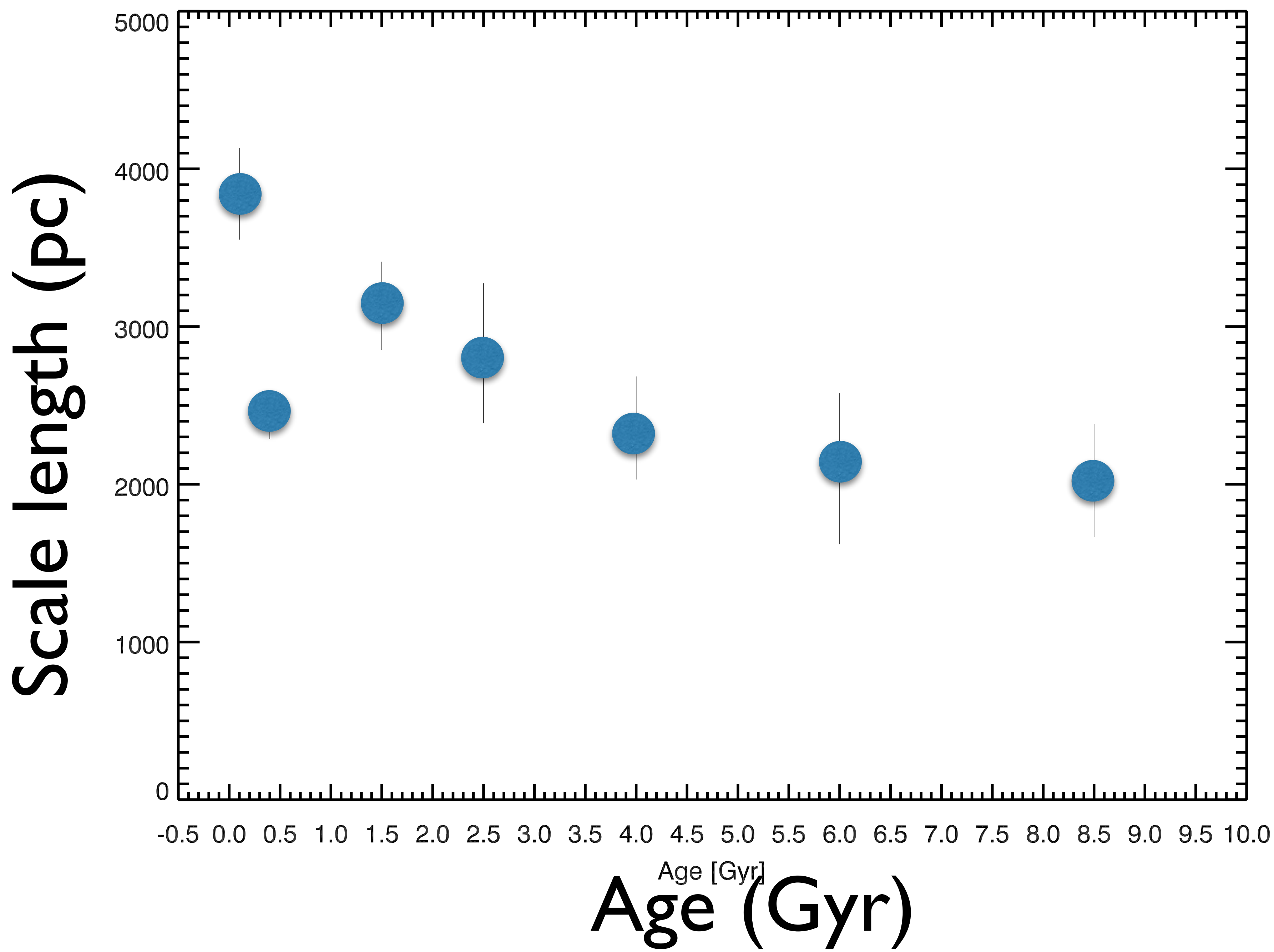


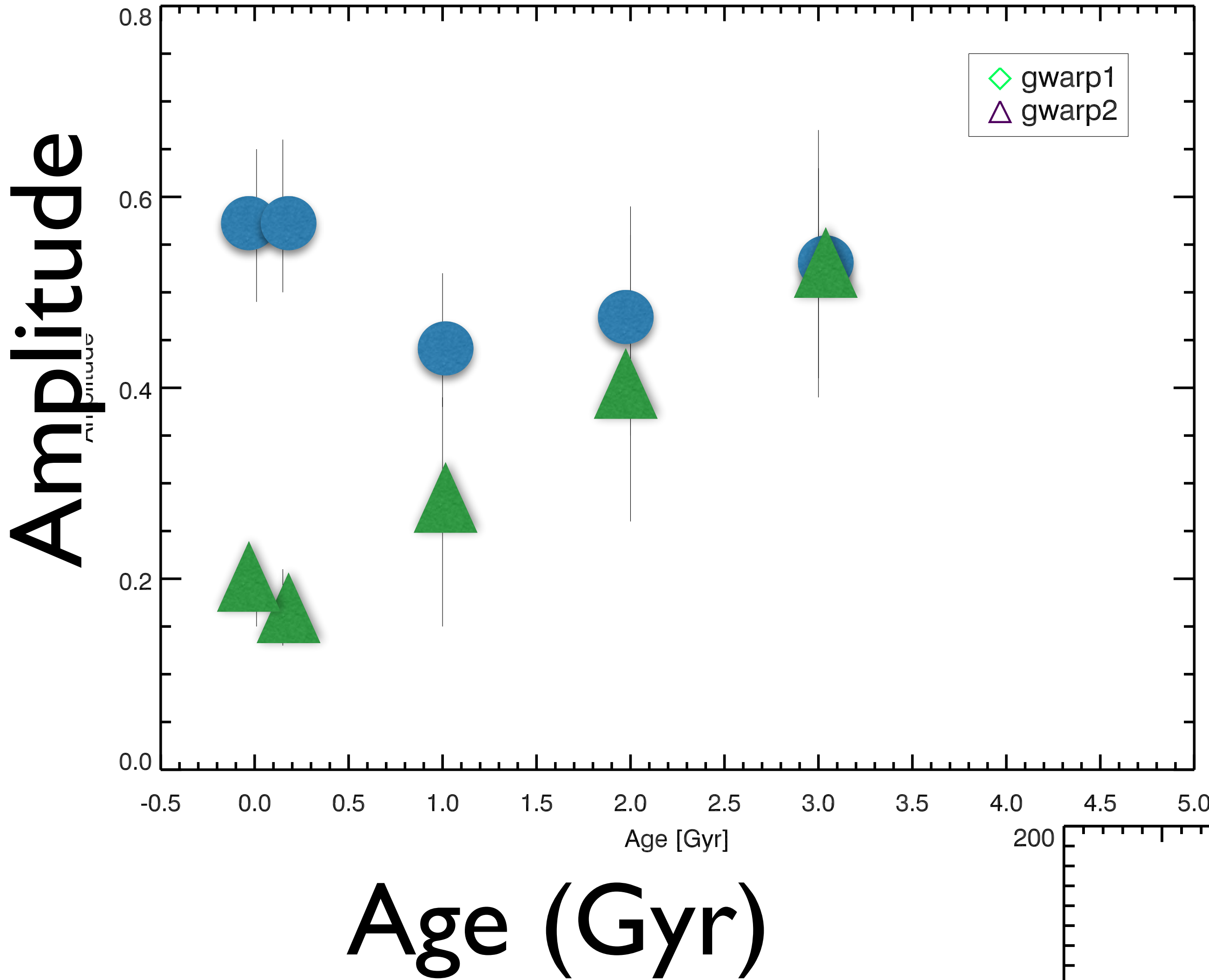
Figure 5. Radial profiles of the scale-height for the mono-age populations (the colourcode indicates the age of each population, from 0 in blue to 11 Gyr in red). The solid lines correspond to the radial range up to R_{95} (radius containing 95% of stars of a given population), the dashed lines extend out to R_{98}. The upper shows our three quiescent galaxies, while the lower row shows thoe with an active merger history.

Martig, Minchev & Flynn, 2014

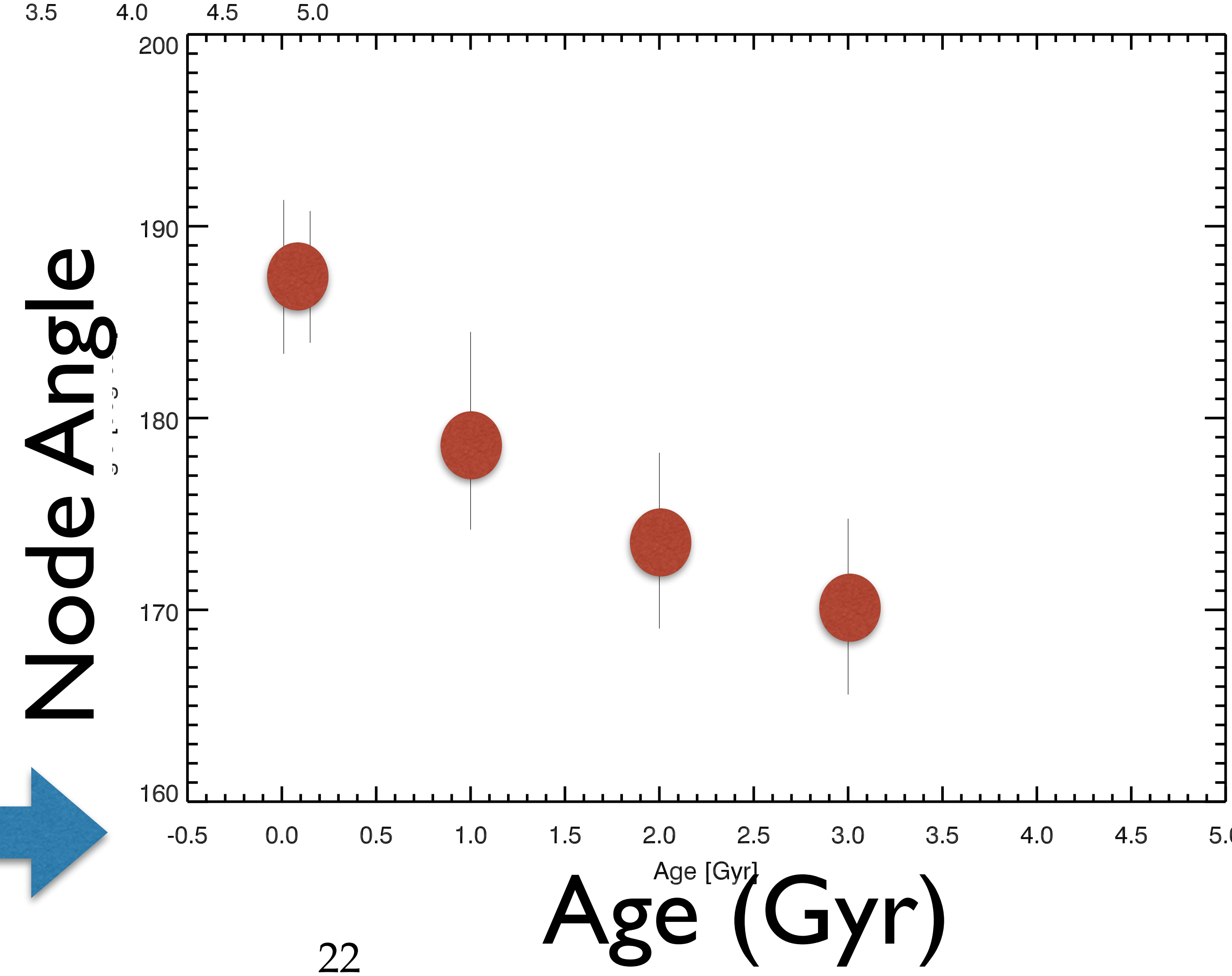


Thin disc scale length changing with age, from 4 kpc to ~2 kpc

Amores, Robin, Reylé, in prep

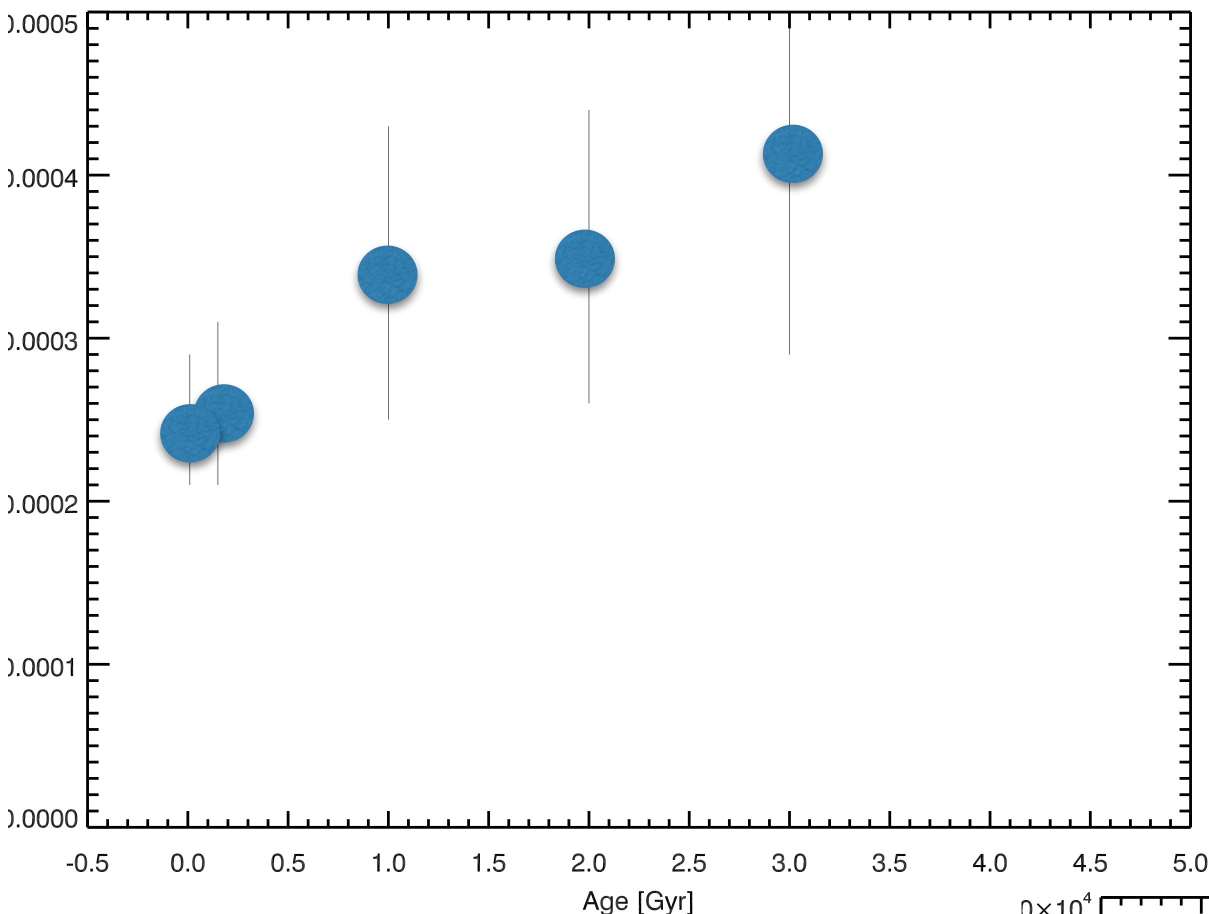


Warp : slope changing with age
+ asymmetry

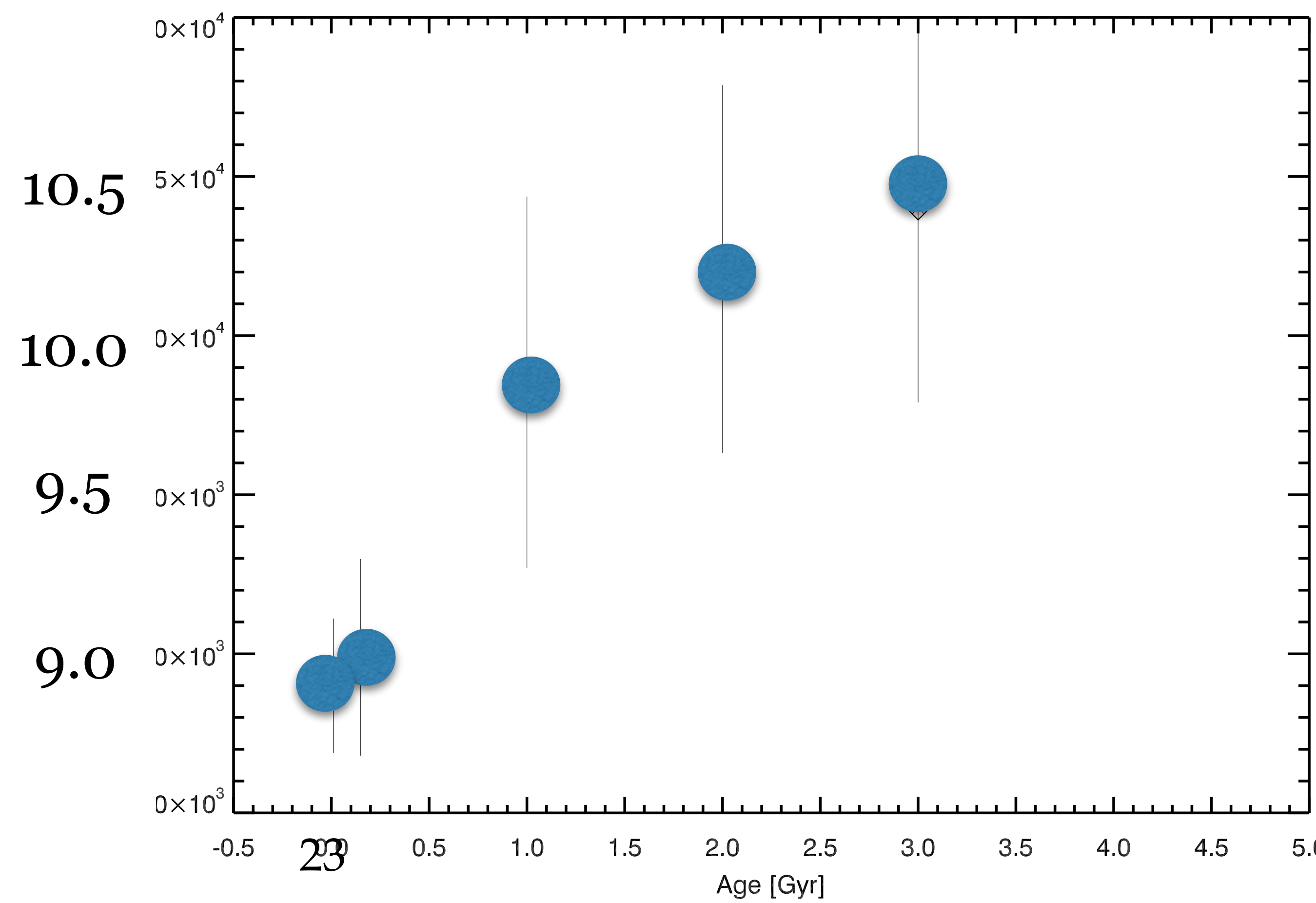


Angle changing with age
~5°/Gyr

Flare slope

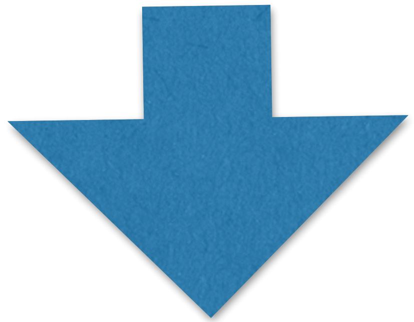


R_flare



Thin-thick disc relation

- Thick disc formation outside-in ! Lehnert+ 2009, Bournaud + 2009 : gas turbulent phase. Explain well the mixing (absence of radial gradient) seen in the thick disc abundances in APOGEE (Hayden+ 2014)
- 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



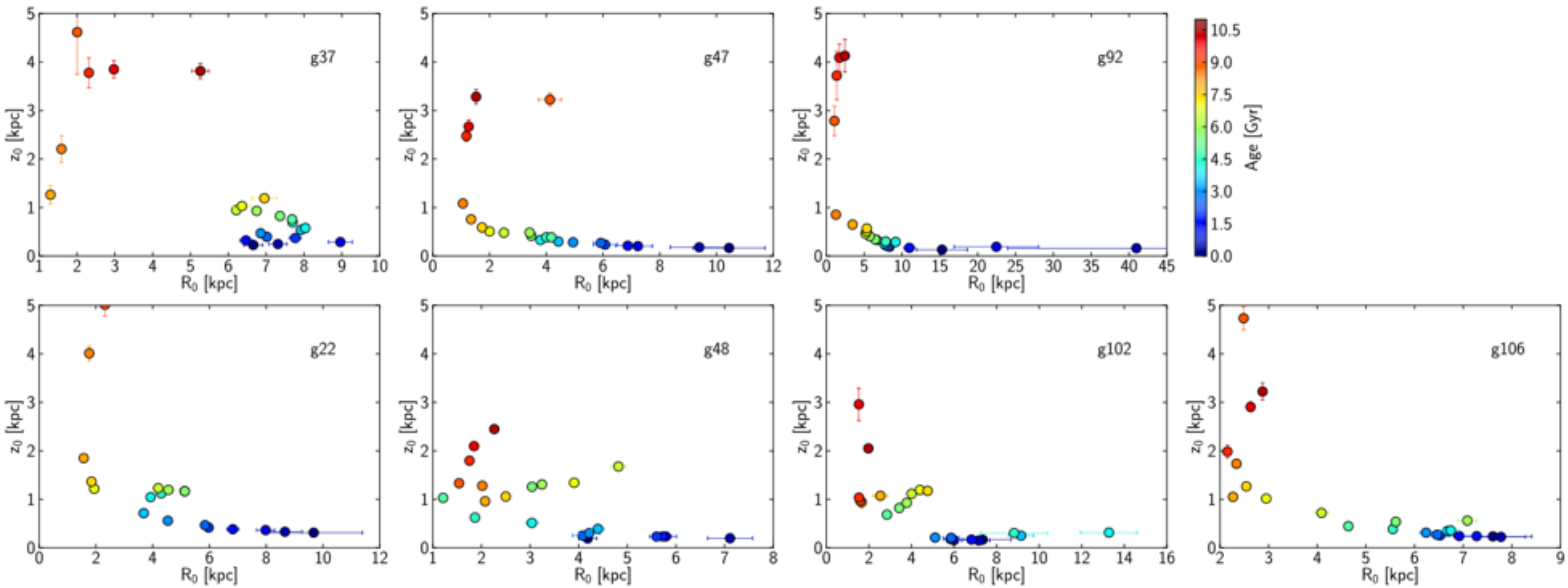
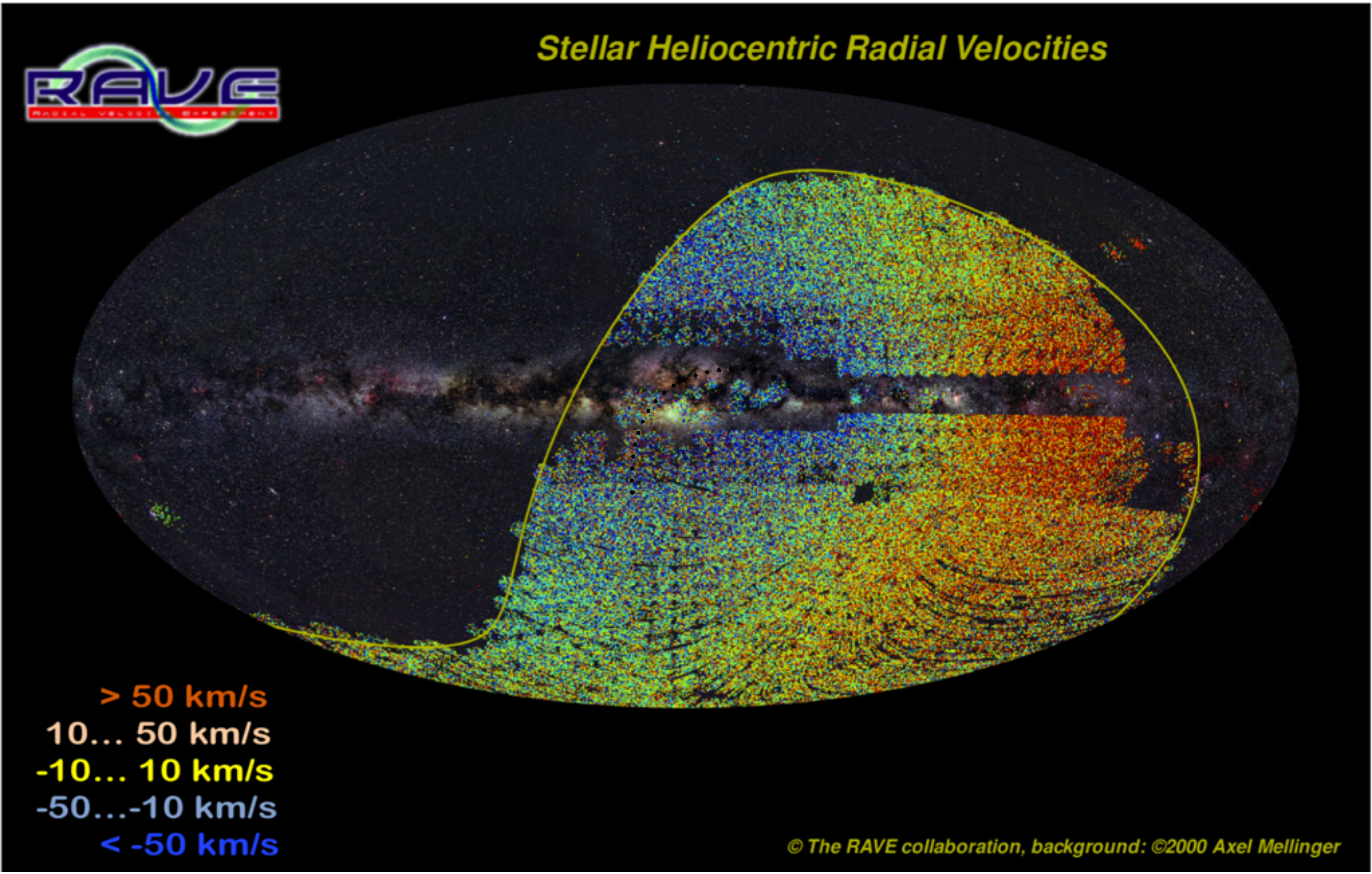


Figure 10. Scale-height as a function of scale-length for mono-age populations in the 7 simulated galaxies. The scale-heights are measured at a radius of $2R_d$. The colourcode and panel order are the same as in Figure 5. We find that the observed anti-correlation between scale-height and scale-length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

Martig, Minchev & Flynn, 2014

On-going applications to spectroscopic surveys

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

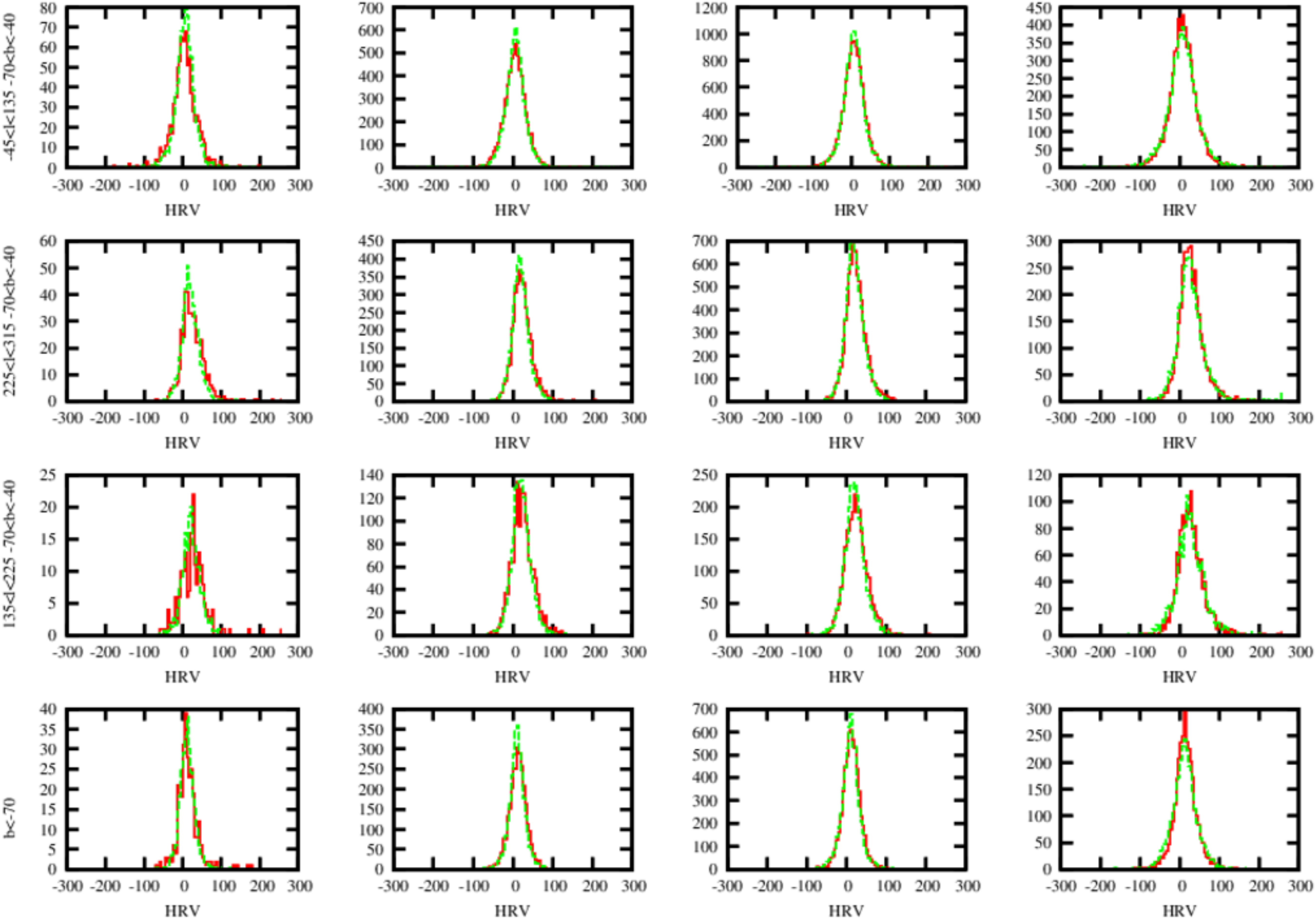

Stellar Heliocentric Radial Velocities
RAVE
> 50 km/s
10… 50 km/s
-10… 10 km/s
-50…-10 km/s
< -50 km/s
© The RAVE collaboration, background: ©2000 Axel Mellinger

Kinematics from RAVE

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

Kinematic modelling

- Bienaymé et al, 2015 : fit a Stackel potential to the BGM potential => 3 integral of motion
- Asymmetric drift variation as a fct of z
- Fit solar motion and age/velocity dispersion relation


-45<l<135 -70<b<-40
225<l<315 -70<b<-40
135<l<225 -70<b<-40
b<-70
HRV

Thick disc velocities

Age	Vcirc	S_W
12 Gyr	184 ± 5 km/s	50 ± 2 km/s
10 Gyr	207± 2 km/s	30 ± 0.6 km/s

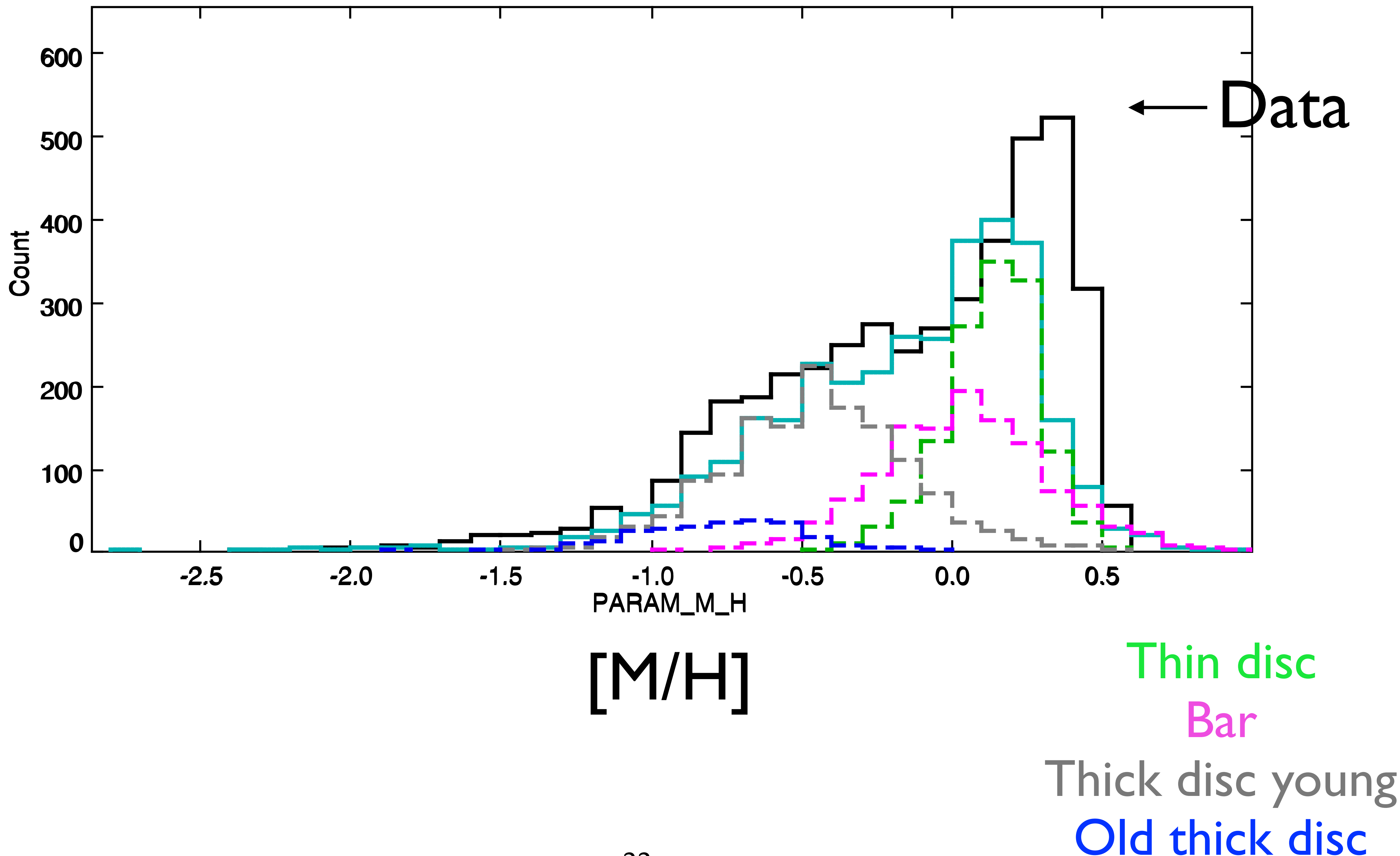
- *Contraction indicated by the scale lengths and heights (from photometry, star counts)*
- *Also indicated by the speed up of the circular velocity and by velocity dispersions*

Robin, Bienaymé, Fernandez-Trincado, in prep

APOGEE

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

Bulge fields : 0°<l<18°, -14°<b<14°



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

Perspectives

- Simulate large scale spectroscopic surveys with their selection function for a thorough comparison to validate/invalidate the scenario
- Towards a dynamically consistent non-axisymmetric model (Fernandez-Trincado et al in prep)
- Compare with Gaia data : explore the failures of the scenario
- Model on line : new web service access very soon !