Statistical analysis of large scale surveys for constraining the Galaxy evolution

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Outline

- Introduction
  - Thick disc
- The Besançon Galaxy Model
- SEGUE data
  - SEGUE plates
  - Simulations
  - Sample selection
  - Results from the SEGUE analysis
    - The metallicity distribution
    - Distances
    - MCMC-ABC analysis
- Conclusions
- Perspectives
- ~~Preliminary analysis of the Gaia-ESO survey~~

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Milky Way thick disc

- Milky Way → We can study the chemical composition and the Galactic dynamics based on individual star measurements.
- The thick disc → Old component of the Galaxy

  → Remnant of the early galaxy formation and evolution.
- The first stages of galaxy formation are printed in the chemical and kinematic properties of the thick disc.
- To understand the Milky Way formation and evolution it is crucial to understand thick disc formation.

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Besançon Galaxy Model

SFR : Thin disc – Constant
Thick disc – One burst
Halo - One burst

	Age (Gyr)	$[\frac{Fe}{H}]$ (dex)	$\frac{d[Fe/H]}{dR}$
Disc	0–0.15	0.01 ± 0.12	
	0.15–1	0.03 ± 0.12	
	1–2	0.03 ± 0.10	
	2–3	0.01 ± 0.11	−0.07
	3–5	−0.07 ± 0.18	
	5–7	−0.14 ± 0.17	
	7–10	−0.37 ± 0.20	
Thick disc	11	−0.78 ± 0.30	0.00
Stellar halo	14	−1.78 ± 0.50	0.00

Robin et al. (2003)

Thick disc → Modified exponential
(parabolic + exponential)

- A short scale length: ~ 2.3 kpc
- Scale height: ~ 530 pc
- Position of the change: ξ ~ 660 pc

Robin et al. (2014)

Age metallicity relation: Haywood (2006)

Thin disc:
Implicit vertical metallicity gradient:
~ -0.06 dex kpc^{-1}

Age-scale height relation

Age-metallicity relation

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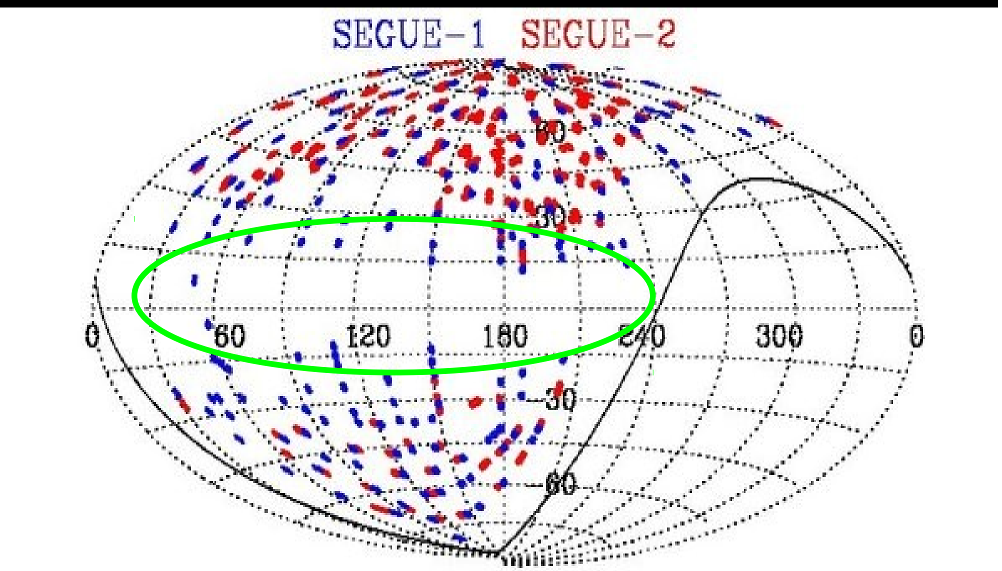
Data

- Low latitude plates of the SEGUE survey.



(http://www.sdss3.org/)

Table 5.1:
SEGUE survey plates used for the present analysis

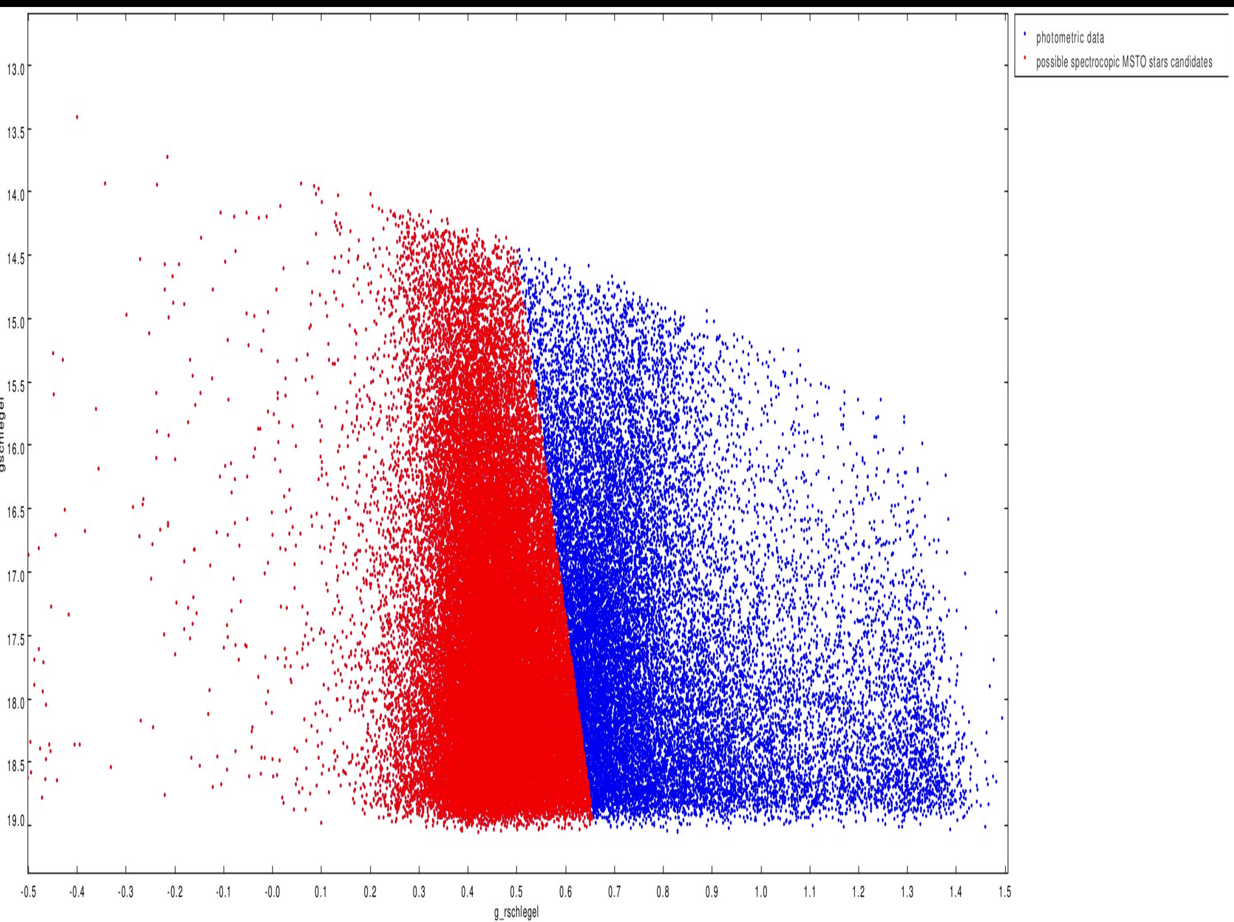
Plate bright/faint	l (°)	b (°)	Ra (°)	Dec (°)
2534/2542	50	14	277.60	21.33
2536/2544	70	14	286.66	39.11
2537/2545	110	10.5	334.17	69.39
2538/2546	110	16	323.07	73.64
2554/2564	94	14	302.97	60.01
2555/2565	94	8	312.39	56.59
2556/2566	94	-8	330.15	45.06
2668/2672	187	-12	79.49	16.61
2678/2696	187	8	98.13	26.67
2681/2699	178	-15	71.50	21.98

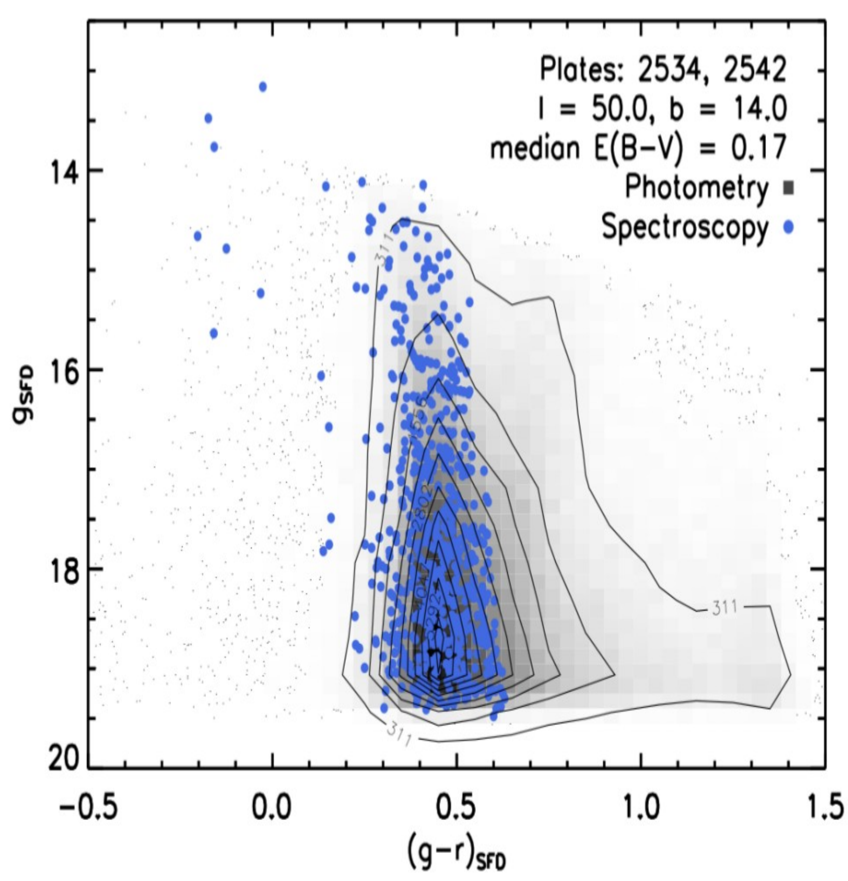
- Spectroscopy (dr8)
  - Bright (g = 15 - 18) and faint (g = 17.5 - 19.5) plates are treated separately.
- Simulations
  - Correct the magnitudes and color of stars with modified extinction model. Martins et al. (submited)
  - We apply the same selection function to simulations (Selection of the stars that will receive fibers).
  - S/N and spectral parameters errors are simulated.
  - Errors are 0.23 dex, 180 k and 0.24 dex respectively for metallicity, effective temperature and log g (Smolinski et al. (2011))
- Compare to observations → selected stars in bins of g and g-r.

Sample selection

Main Sequence Turn-Off stars

- Follow the low latitude sample selection (Cheng, J. Y., Rockosi, C. M., Morrison, H. L., et al. 2012, ApJ, 746, 149)

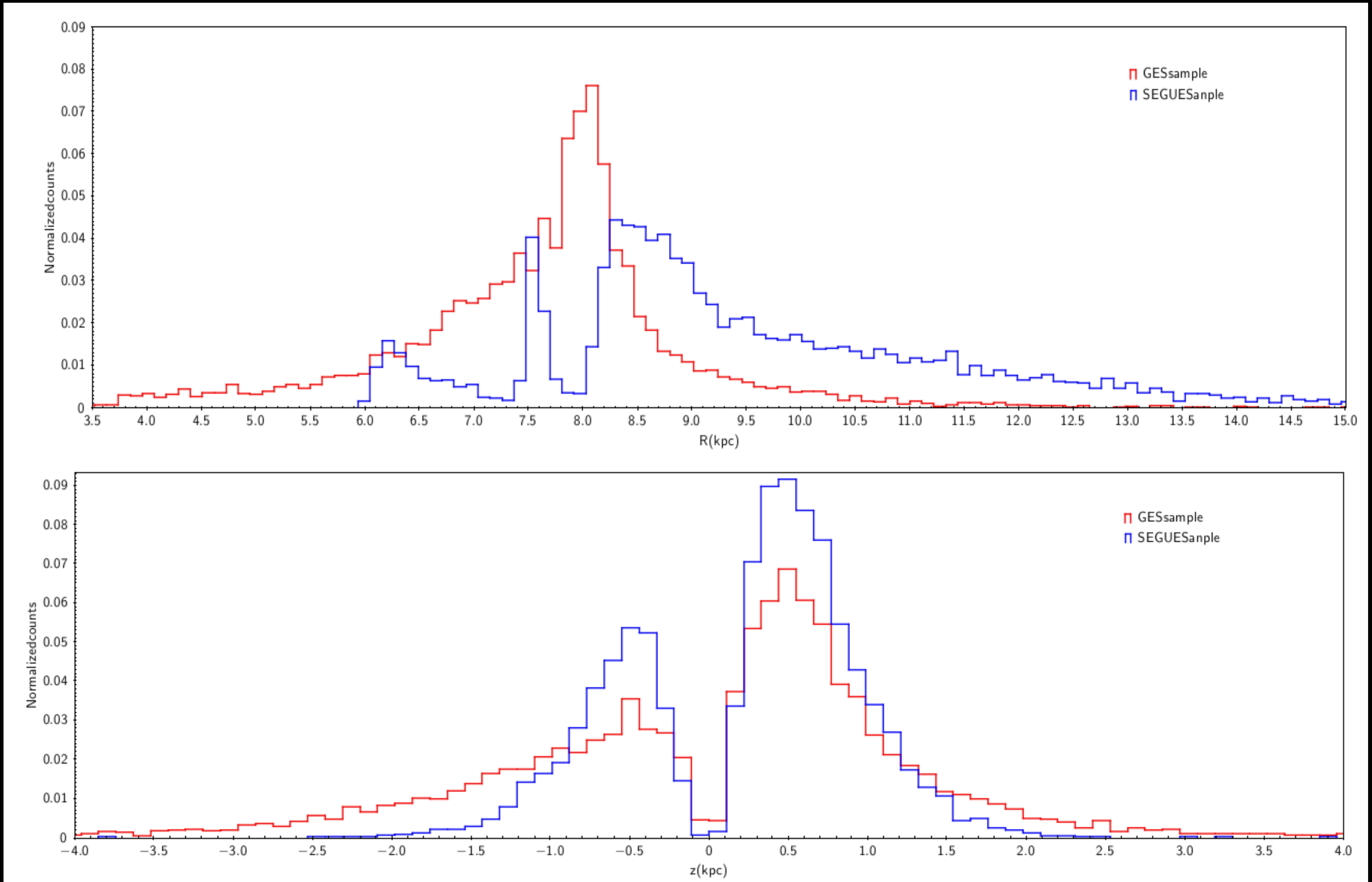




Spatial coverage

- We cover regions: $6.0\ \text{kpc} < R_{gal} < 14.0\ \text{kpc}$

  $0.15\ \text{kpc} < |Z| < 1.5\ \text{kpc}$



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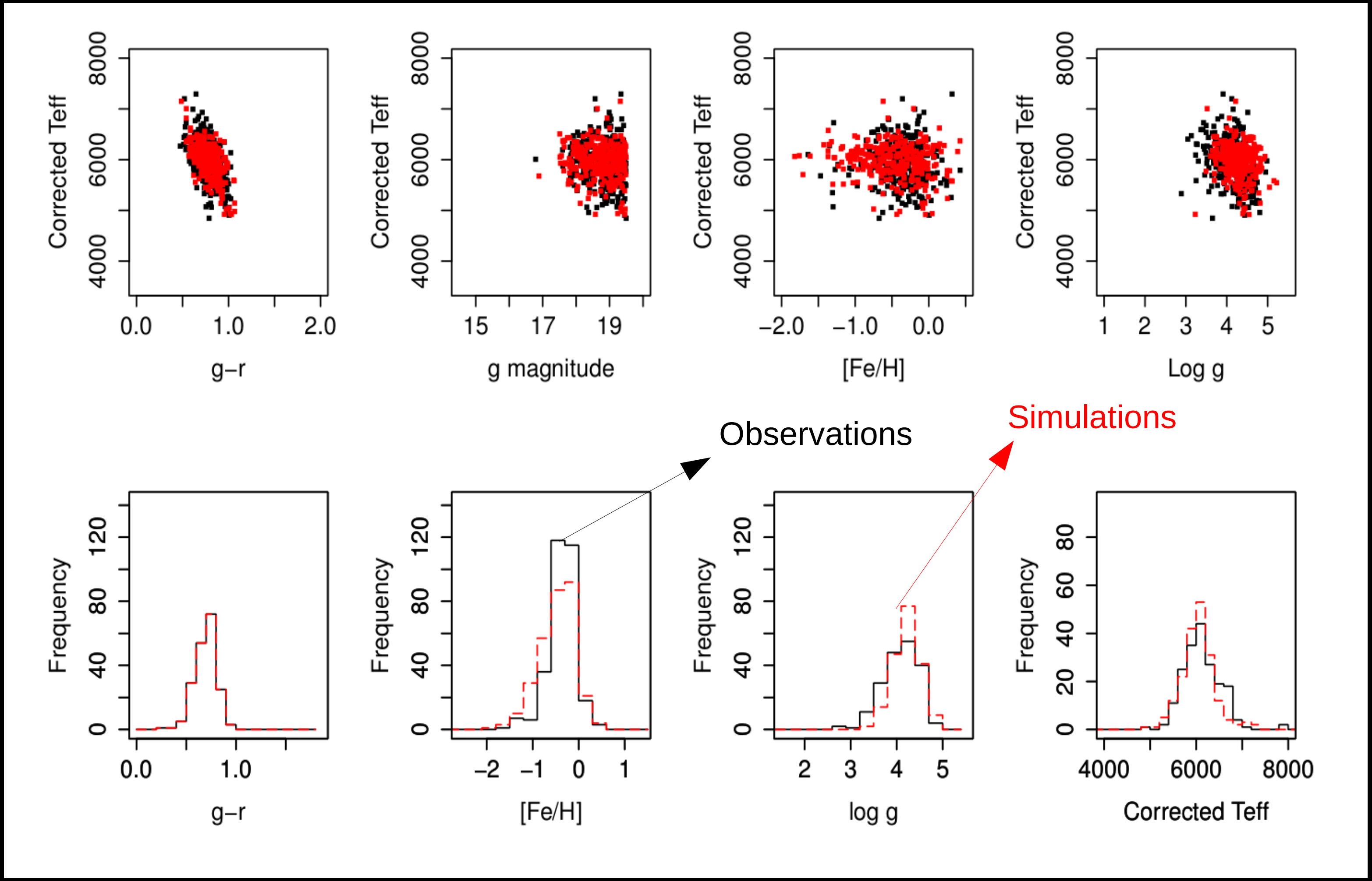
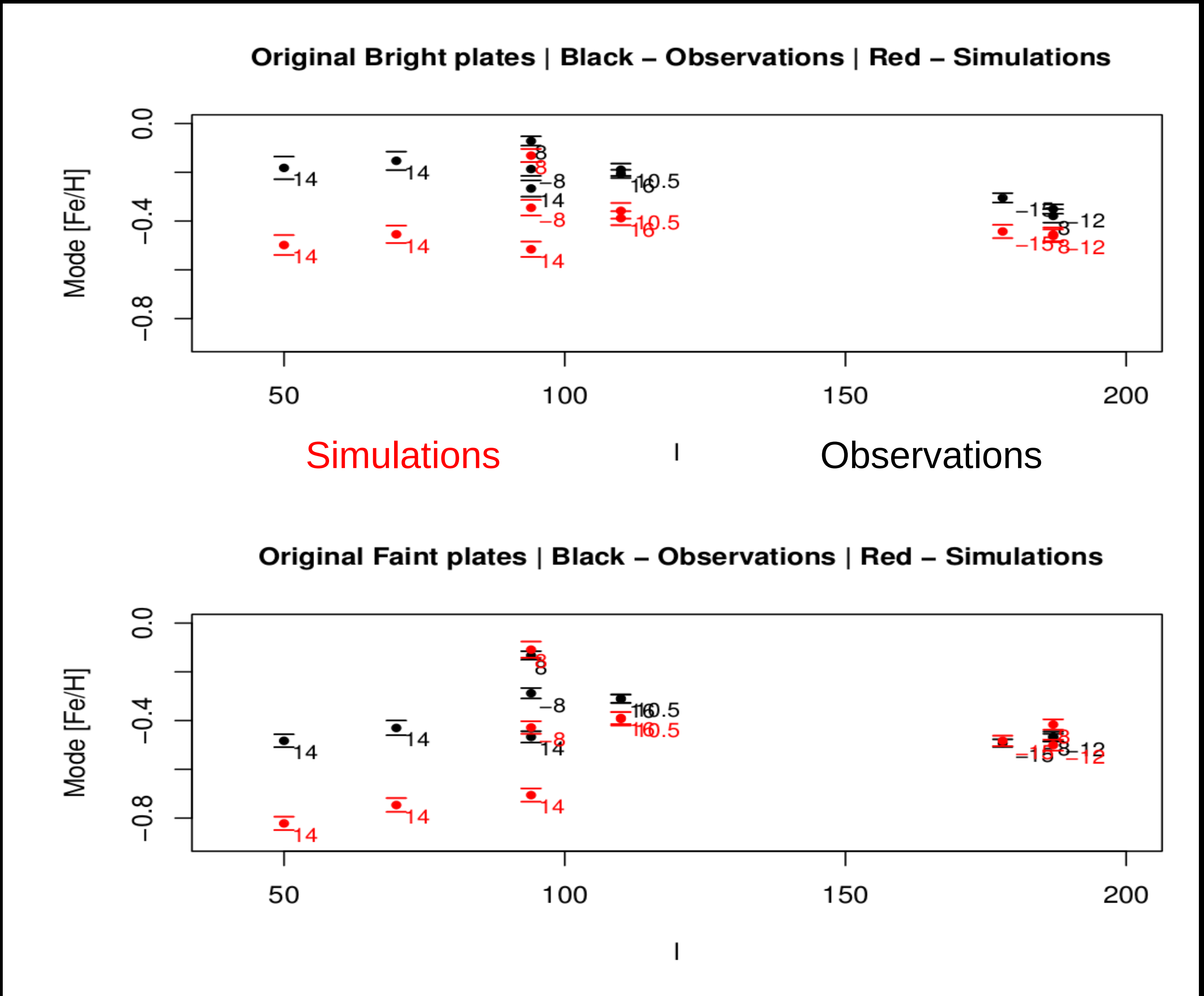
Observations vs simulations

Faint plate → l = 110° b = 10.5°



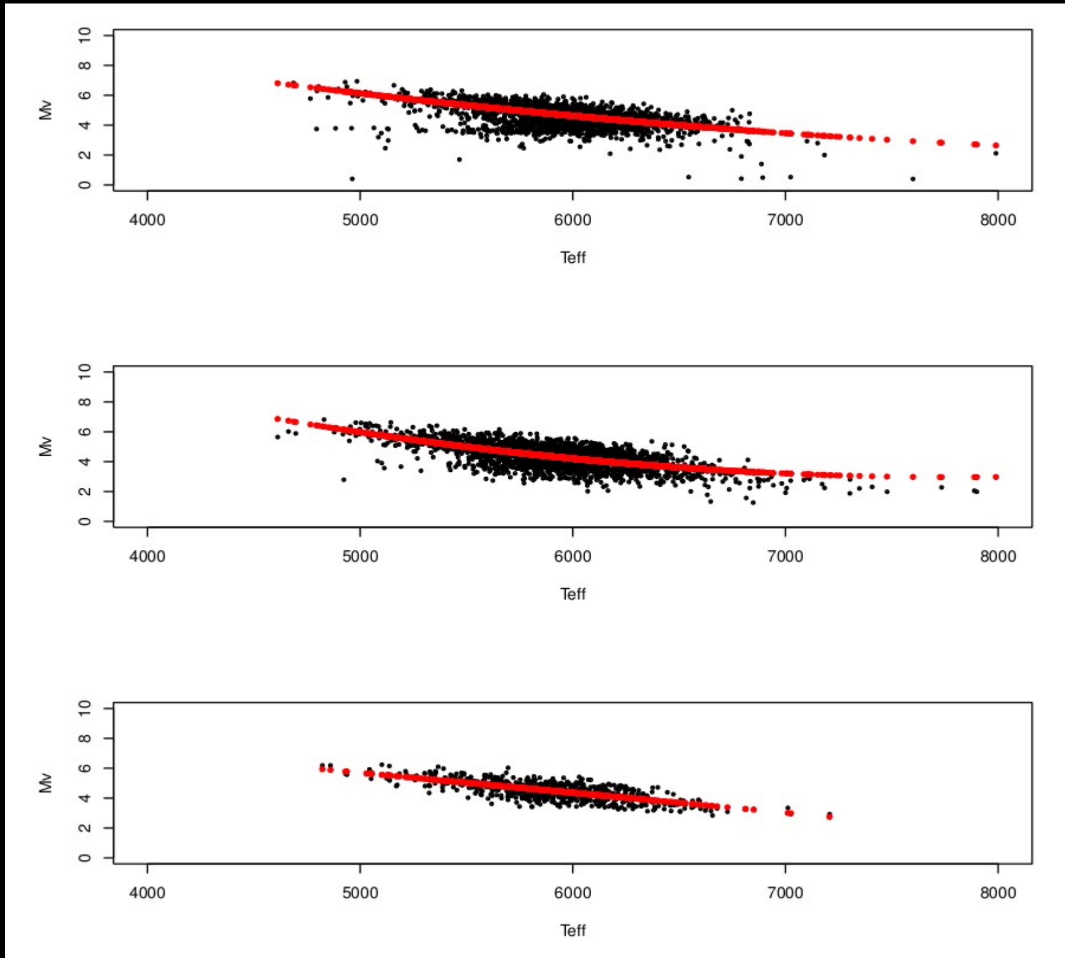
Observations vs simulations

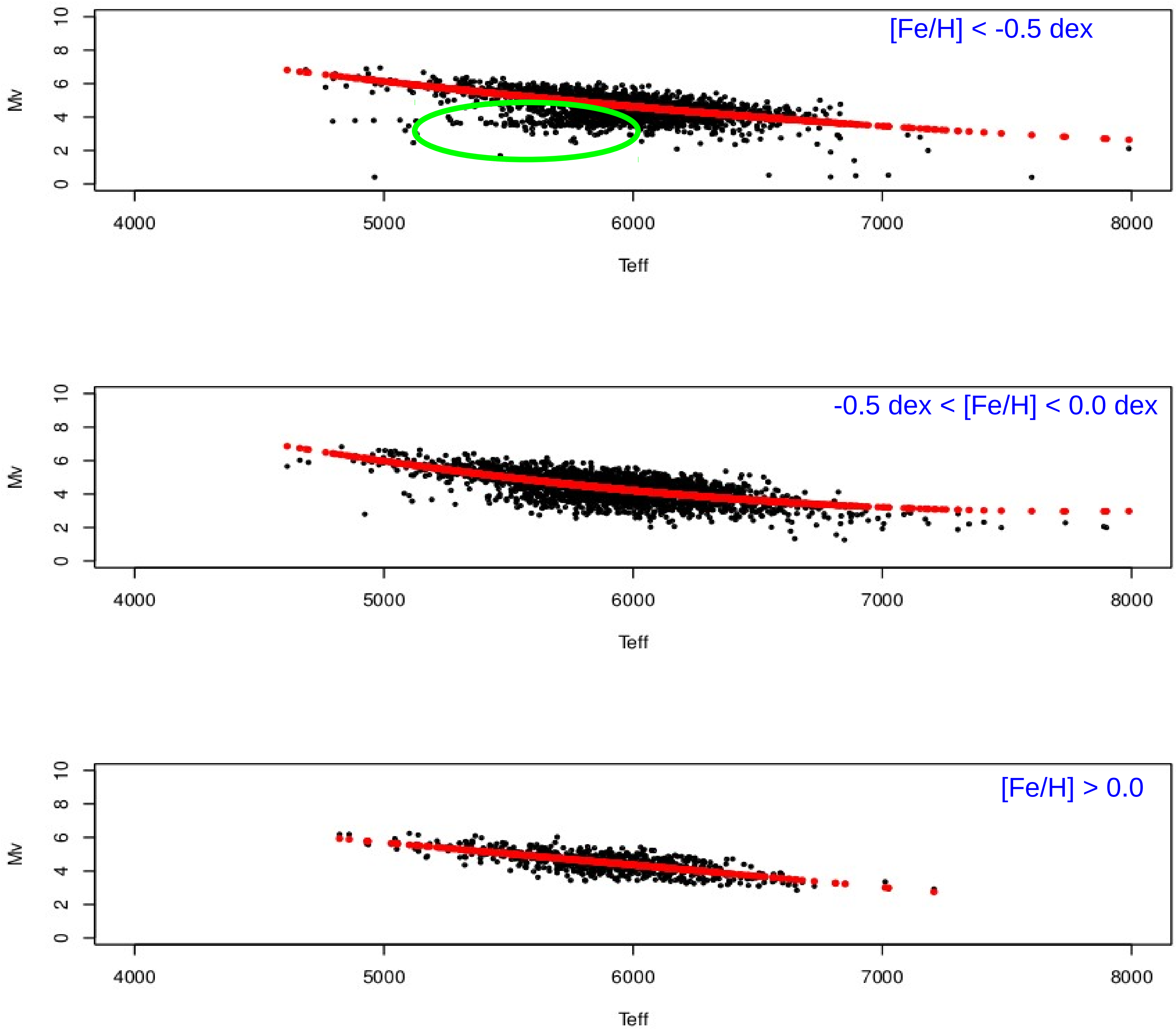


Distances

- Main Sequence Turn-Off stars ➢ from the model we fit a relation between temperature T_{eff} and absolute magnitude (M_V).
- The relation is established independently in three metallicity bins.

- [Fe/H] < -0.5 dex →
- -0.5 dex < [Fe/H] < 0.0 dex →
- [Fe/H] > 0.0 →

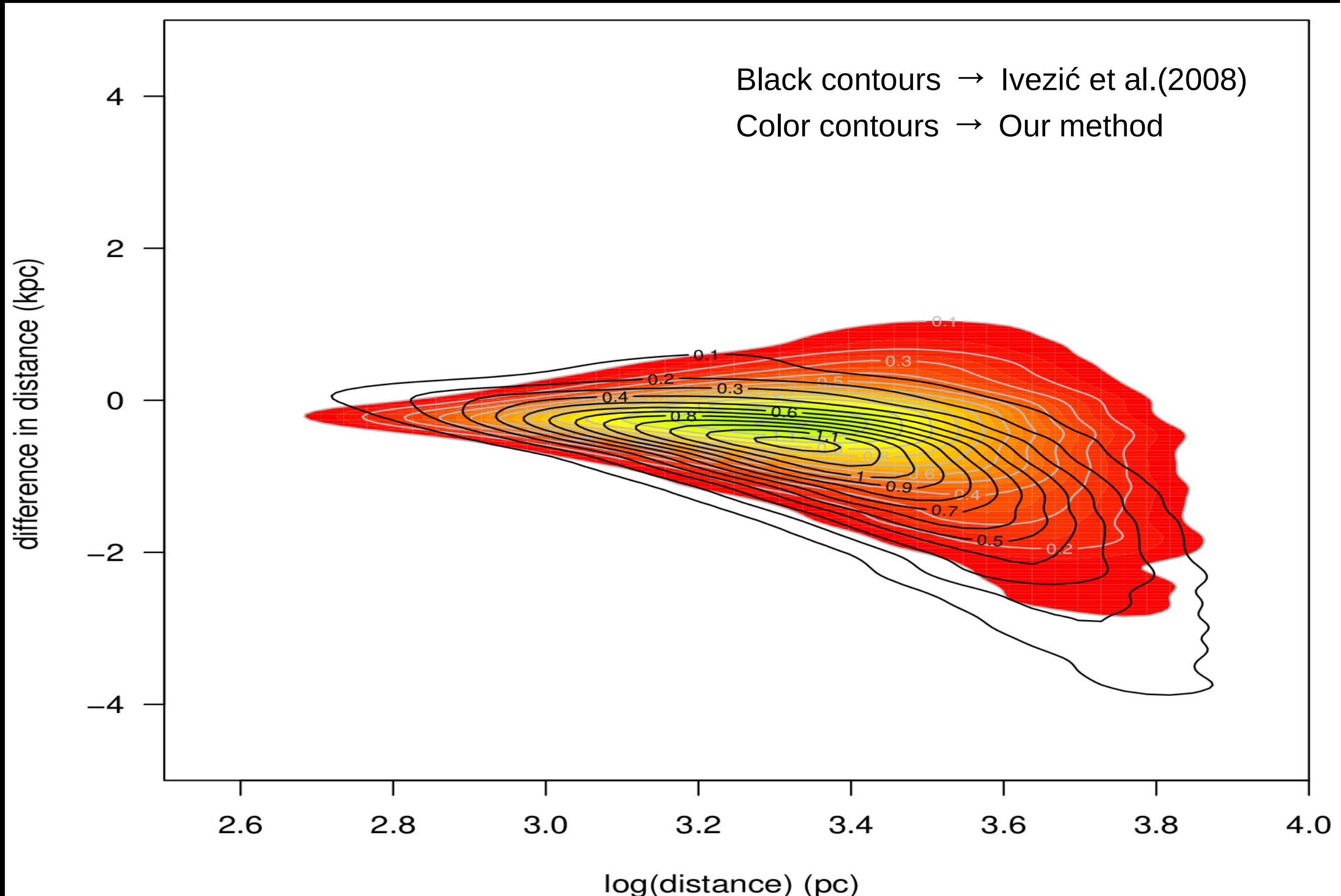



[Fe/H] < -0.5 dex
-0.5 dex < [Fe/H] < 0.0 dex
[Fe/H] > 0.0
Mv
Teff
0
2
4
6
8
10
4000
5000
6000
7000
8000

Distances

- Compute the absolute magnitude for the obs/sim
  - Compute the distance modulus.
  - Extinction is taken in account.
- The same bias
- A clear bias

  d > 4.0 kpc



Ivezić c, Ž., Sesar, B., Jurić c, M., et al. 2008, ApJ, 684, 287

Fitting method

- We use the log-likelihood **(Bienaymé et al. 1987)** .

$$L_r = \sum_{i=1}^{N} q_i \left(1 - R_i + \ln\left(R_i\right)\right)$$

- The data and simulations are binned in the distance metallicity space.
- The log-likelihood is a statistical distance (pseudolikelihood) so we have to use an ABC/MCMC (Approximate Bayesian Computation) method, where the sampling is done by a Metropolis-Hasting algorithm.

MCMC/ABC Fitting method

For iter=1 to maxiter do
    Repeat
    Generate θ' from the prior distribution π(•)
    Generate z from the likelihood f(•|θ')
    until $\rho \leq \varepsilon$
    set $\theta_i = \theta$
end for

ρ → pseudolikelihood (Distance)
ε → tolerance
z → simulated distribution

Marin, J.-M., Pudlo, P., Robert, C. P., & Ryder, R. 2011

Bin size

- $Bin_{[Fe/H]}$ = 0.25 dex
- $Bin_{distance}$ = 1.0 kpc

Results

- We fit for the thin and thick disc:
    - Local [Fe/H]
    - Radial metallicity gradients
    - Dispersion
- We fit:

i. Thick disc.

ii. Thick disc along with the thin disc

iii. Thick disc along with the old thin disc.

- We have analyzed three cases for point ii.
    - Case 1: We use all fields.
    - Case 2: We don't use the anticenter fields.
        - l = 187°; l = 178°;
    - Case 3: We don't use the inner fields.
        - l = 50°; l = 70°;

Results - Thick disc along with the old thin disc

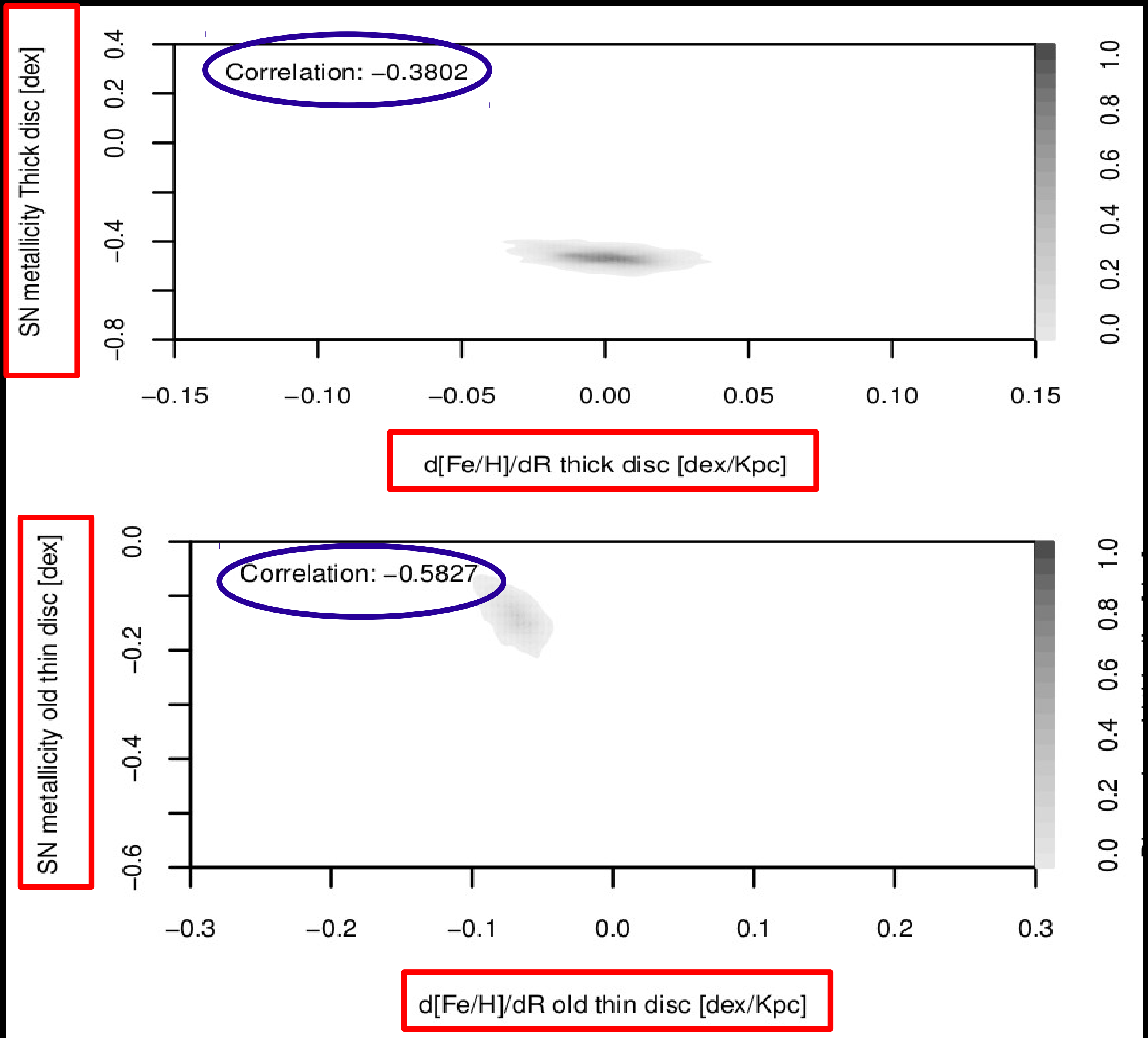
- Considering 10 independent runs:
  - The results are the mean.
  - The σ is the standard deviation.

	case	$[Fe/H]_{SN_{Thick}}$ (dex)	$\frac{d[Fe/H]}{dR}$ (dex kpc^{-1})	Disp (dex)	$[Fe/H]_{SN_{Old\ Thin}}$ (dex)	$\frac{d[Fe/H]}{dR}$ (dex kpc^{-1})	Disp (dex)	$\mathcal{L}$	BIC
All fields	1	-0.465	-0.008	0.319	-0.116	-0.079	0.135	-511.05	
		±0.033	±0.015	±0.029	±0.012	±0.015	±0.011	±16.63	1084.66
No anticenter fields	2	-0.449	0.031	0.319	-0.116	-0.086	0.135	-269.10	
		±0.028	±0.025	±0.032	±0.021	±0.040	±0.011	±9.08	587.18
No inner fields	3	-0.418	-0.030	0.304	-0.113	-0.076	0.135	-440.37	
		±0.024	±0.050	±0.038	±0.017	±0.017	±0.011	±16.10	931.85

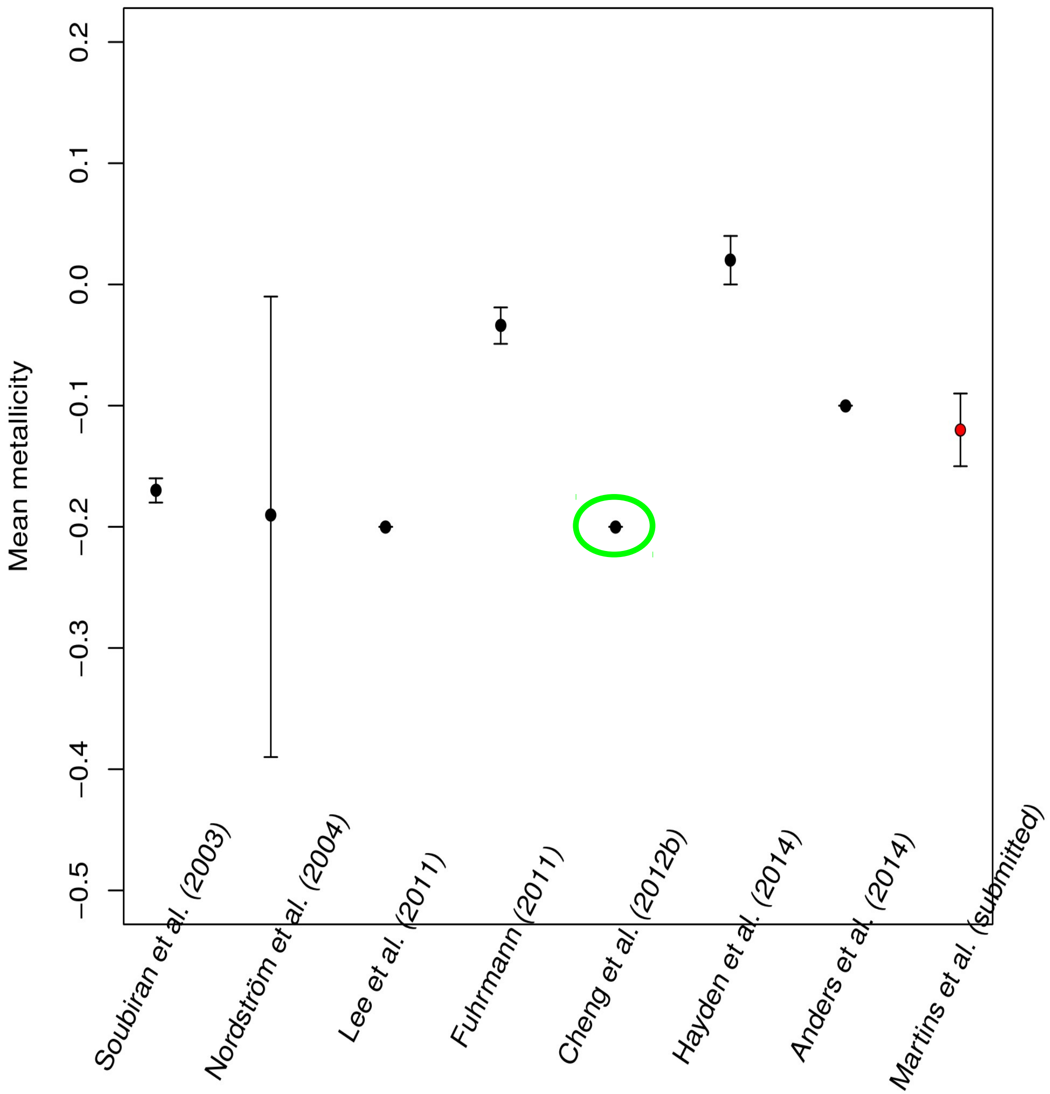
Case 1

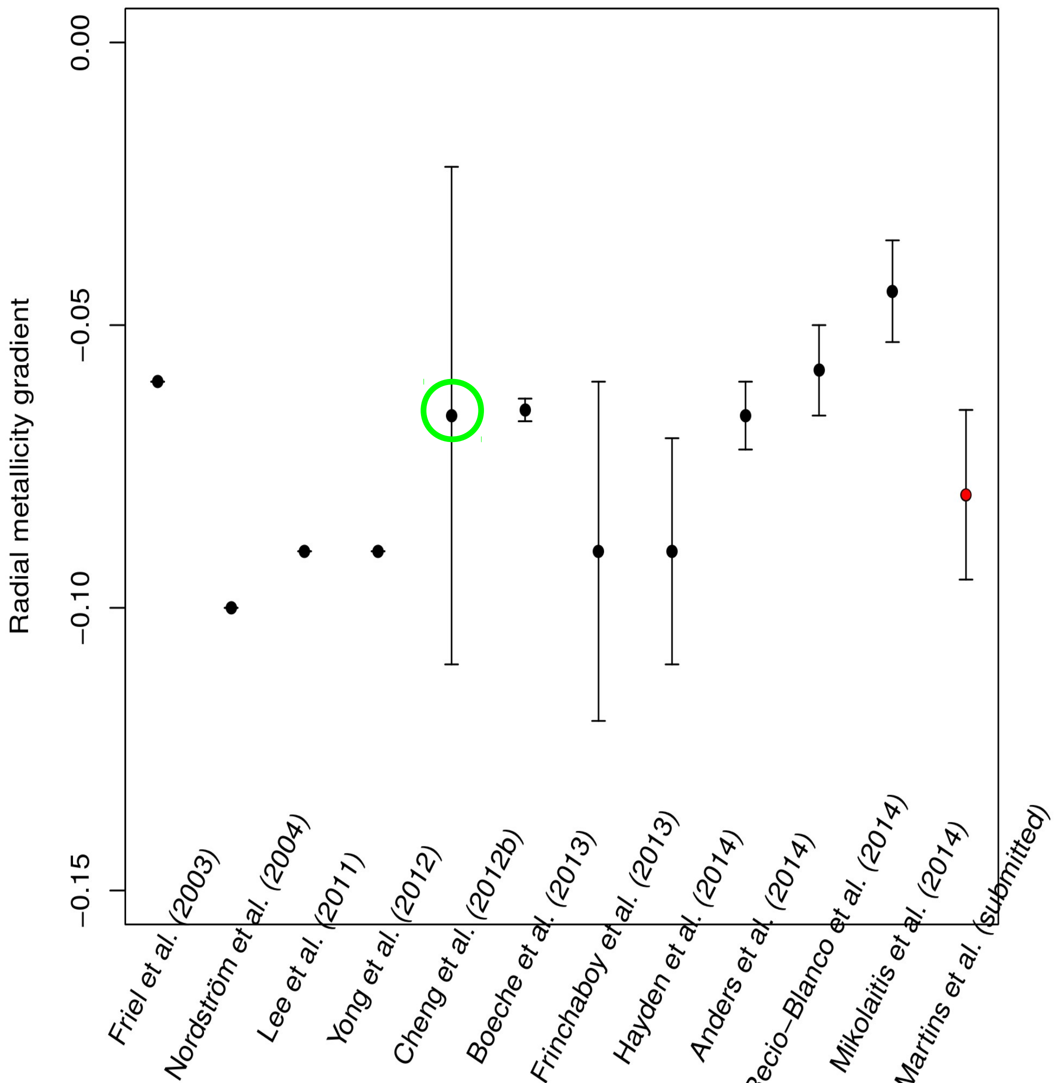
A. M. M. Martins et al. submitted

Correlations

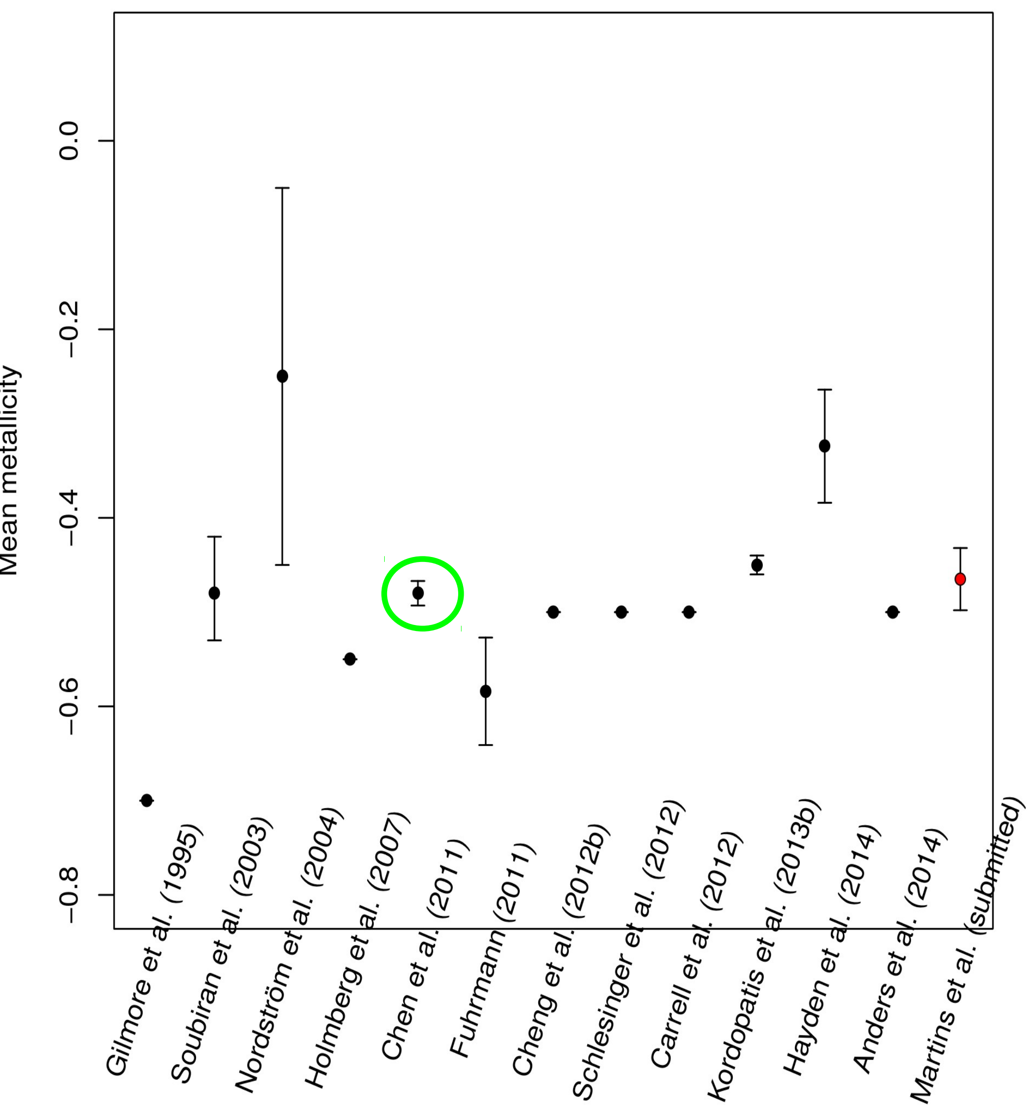


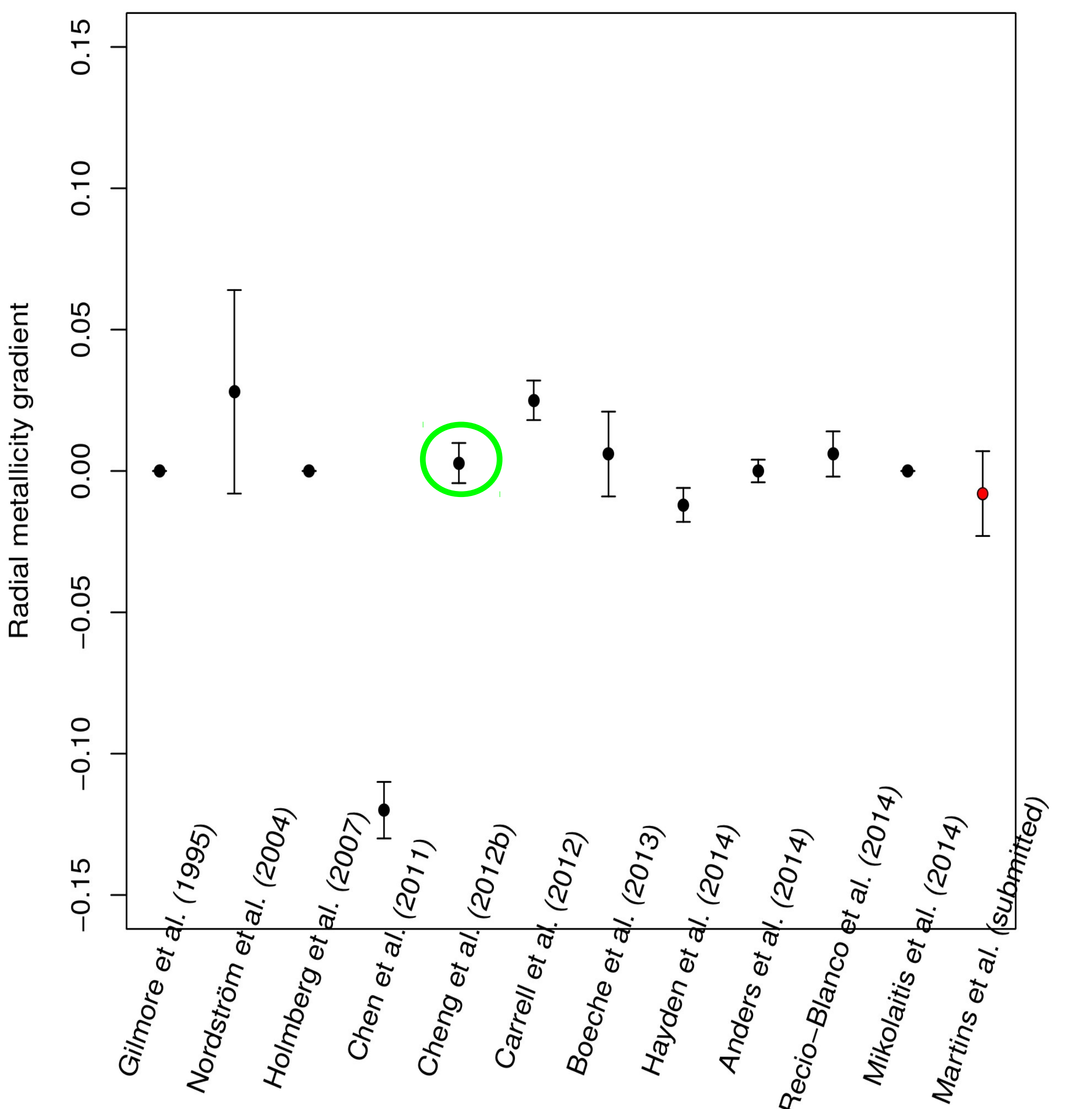
Thin disc metallicity distribution from the literature





Thick disc metallicity distribution from the literature





The age of the thick disc

Case 1 → All fields

Table 8.11:
Sum of the likelihood values, for different ages of the thick disc, for the spectroscopic parameters (MSTO stars) with the fitted parameters.

Age	[Fe/H]	σ	T_{eff}	σ	log g	σ
8 Gyr	-734.31	23.34	-1133.74	49.38	-424.284	17.06
9 Gyr	-693.68	10.78	-1032.26	10.84	-400.93	5.780
10 Gyr	-695.19	15.90	-990.16	39.27	-449.12	14.49
11 Gyr	-695.84	10.09	-969.23	10.22	-388.55	6.63
12 Gyr	-605.94	11.72	-790.60	13.46	-361.15	9.108
13 Gyr	-706.82	13.56	-1025.64	31.84	-448.57	13.79

Results

- If thick disc has a single epoch formation

  → 12 Gyr is the best age for this population.

  → The isochrone from Bergbush and vandenberg (1992) that best fits these data is the one with Fe/H=-0.5 and age of 12 Gyr.

- We tried to fit two radial metallicity gradients in the thick disc adding a parameter R_{change} → Results are compatible with no slope in the thick disc.

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Discussion – Thick disc formation scenarios

- The confirmation of a null radial metallicity gradient in the thick disc
  → **Radial mixing in gas or stars is important**

> ***Gas mixing***

- High SFI → strong turbulent gaseous disc Brook et al. (2004), Lehnert et al (2009), Bournaud et al. (2009), Haywood et al. (2013)

Thick disc was formed in a highly mixed gas producing a chemically homogeneous thick disc

> ***Star + Gas mixing***

- Radial migration (Sellwood & Binney (2002), Schönrich & Binney (2009a), Schönrich & Binney (2009b)) can also flatten gradients
- The radial mixing in a disc can be also a consequence of the minor mergers Kazantzidis et al. (2008), Quillen et al. (2009), Bird et al. (2012).
  - Radial mixing becomes stronger at large |z|. Explains a flat gradient in the thick disc, not found in the thin disc.

> ***Direct accretion of stars*** (Statler (1988), Toth & Ostriker (1992), Quinn et al. (1993), Velazquez & White (1999) and Abadi et al. (2003)).

  - Results cannot rule out this scenario

Conclusions

- The thin disc local metallicity and radial metallicity gradient are in agreement with literature
- The thick disc local metallicity is found to be around -0.5 dex in SEGUE
  - There is no radial metallicity gradient in the thick disc
    - This result indicates the existence of radial mixing in gas or stars
  - An inversion of the thick disc radial metallicity gradient seems less probable

- The method allowed the study of correlations

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Perspectives

- The GES analysis (DR2) will be performed on future releases with larger samples and improved calibrations.
    - Use the [Fe/H] vs [α/Fe] sequence
- Apply the analysis tools and techniques, developed with SEGUE and Gaia ESO survey, to APOGEE.
- Combine the results from different surveys.

It will help to constrain better:

- Vertical metallicity gradients.
- SFH of the thick disc.
- Explore chemical evolution in thick disc phase

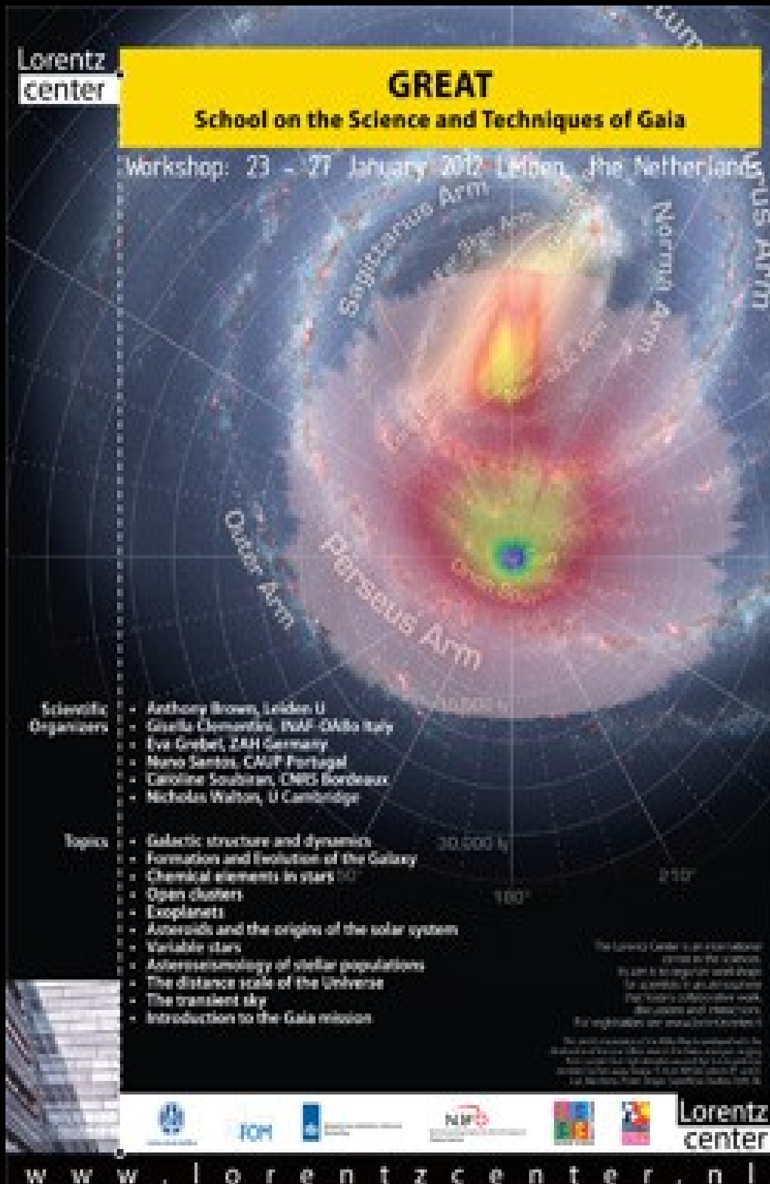
Robin, A. C., Reylé, C., Fliri, J., et al. 2014, Czeka M., Robert C. P., and Martins A. M. M., A&A, 569, A13

- Increase the precision of our results.

Perspectives

- Use of kinematical data combined with metallicity distributions to understand the thick disc formation.
  - Study the rotational velocity as a function of metallicity
  - $\sigma_{u,v,w}$ as a function of metallicity
  - Study the eccentricity as a function of metallicity

Thanks



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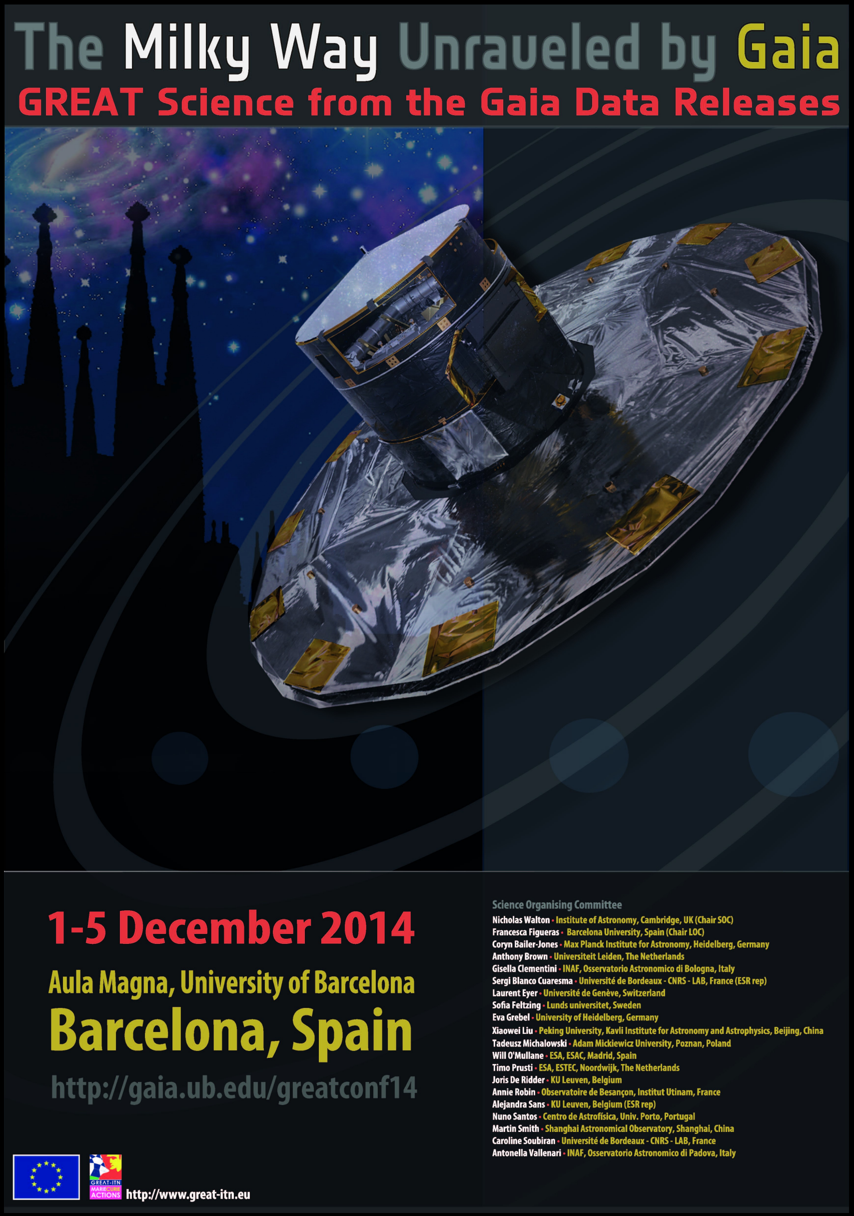

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