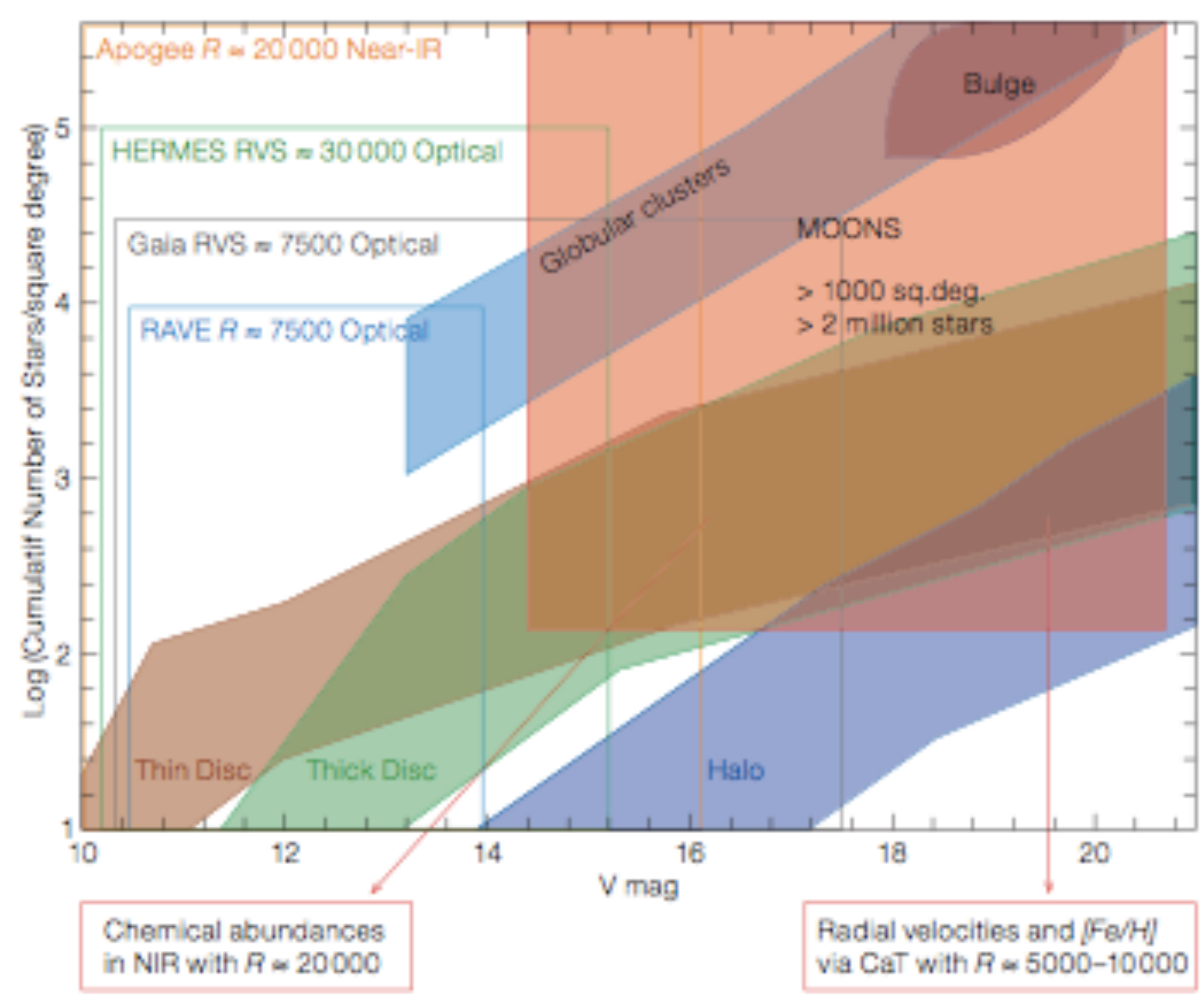
Galactic stellar populations with MOONS (II) :

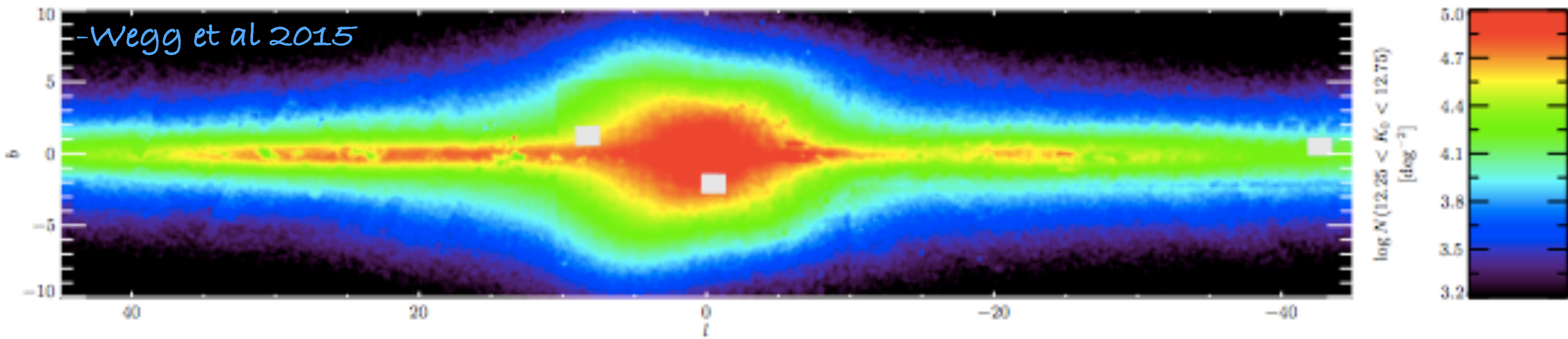
some questions

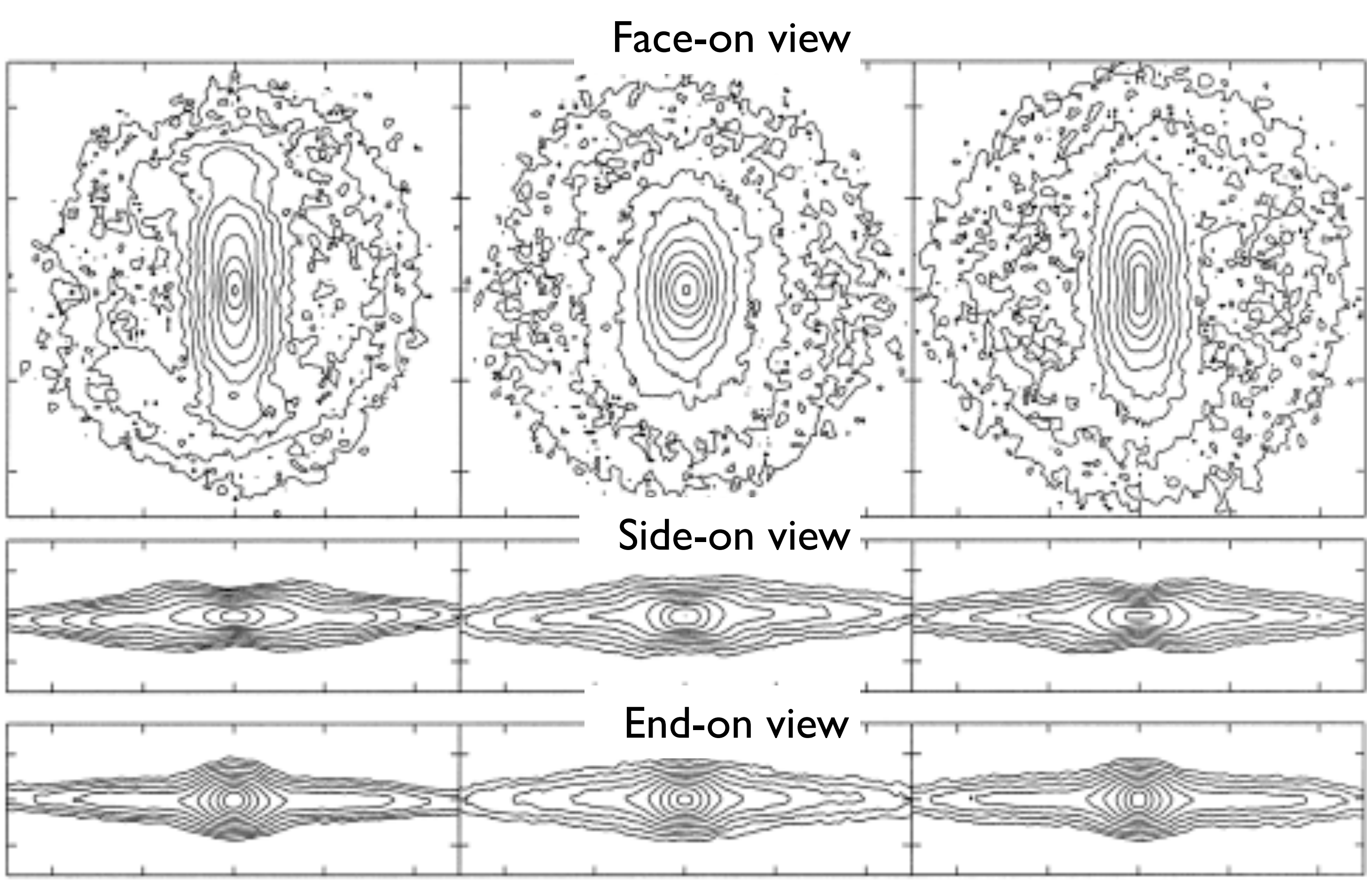
P. Di Matteo, GEPI, Observatoire de Paris-Meudon

1. On the disc origin of the Milky Way bulge (nature of the metal-poor component & classical bulge)
2. On the Galactic globular cluster system
3. On the accreted stars in the Galaxy



ON THE DISC ORIGIN OF THE MW BULGE



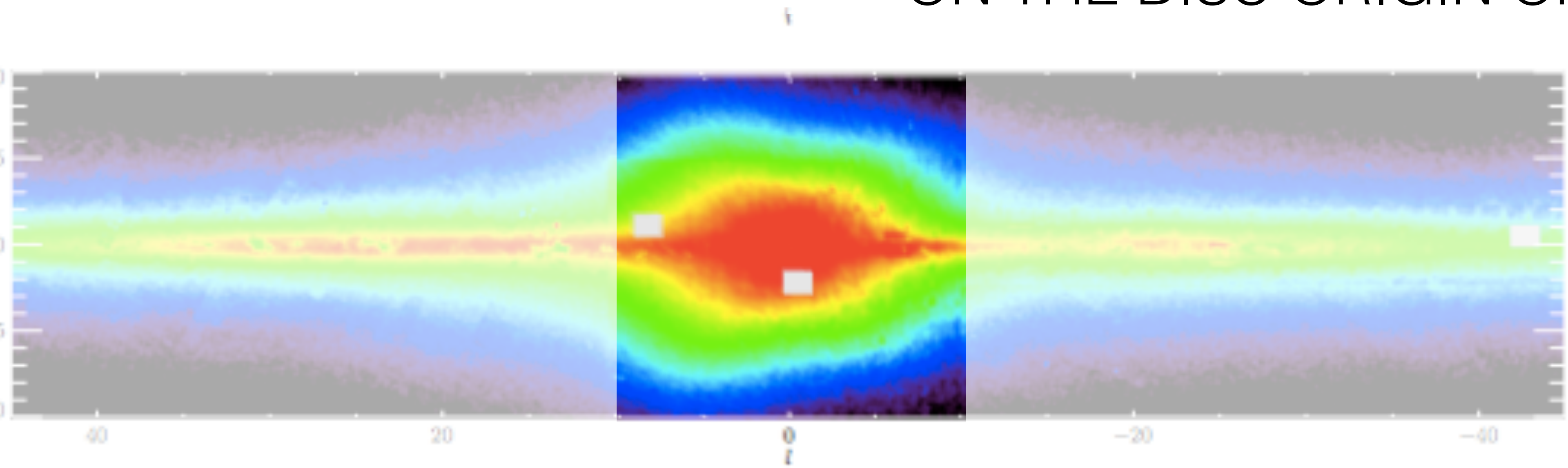


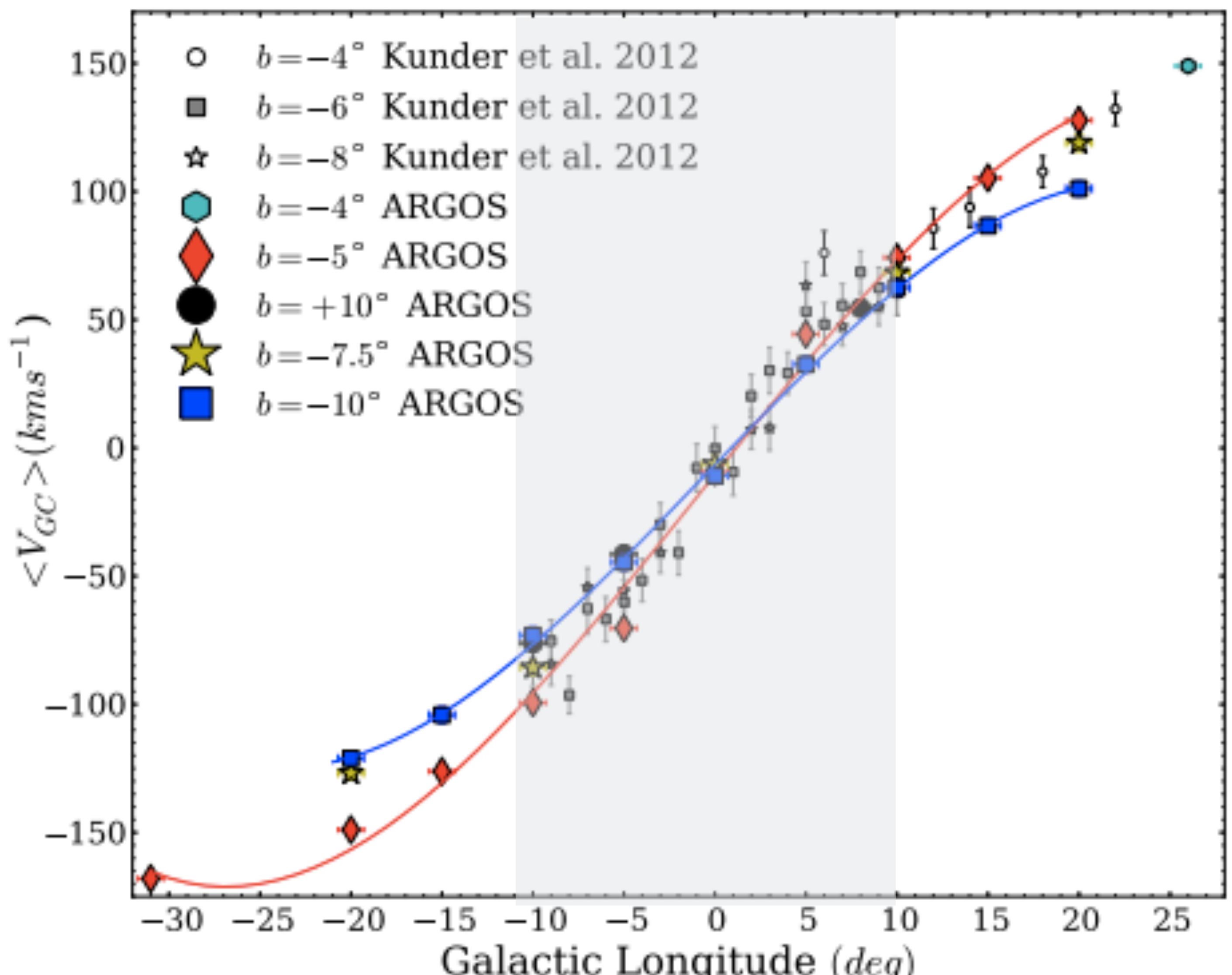
Athanassoula & Misiriotis 2002

The Milky Way bulge has a boxy/peanut shaped structure.
These structures are not rare, since they are present in about half of edge-on disc galaxies (*see Lutticke et al. 2000*)

This structure constitutes the innermost thick part of a longer and flatter bar, extending up to about 5 kpc from the Galaxy centre

ON THE DISC ORIGIN OF THE MW BULGE





Ness et al 2013

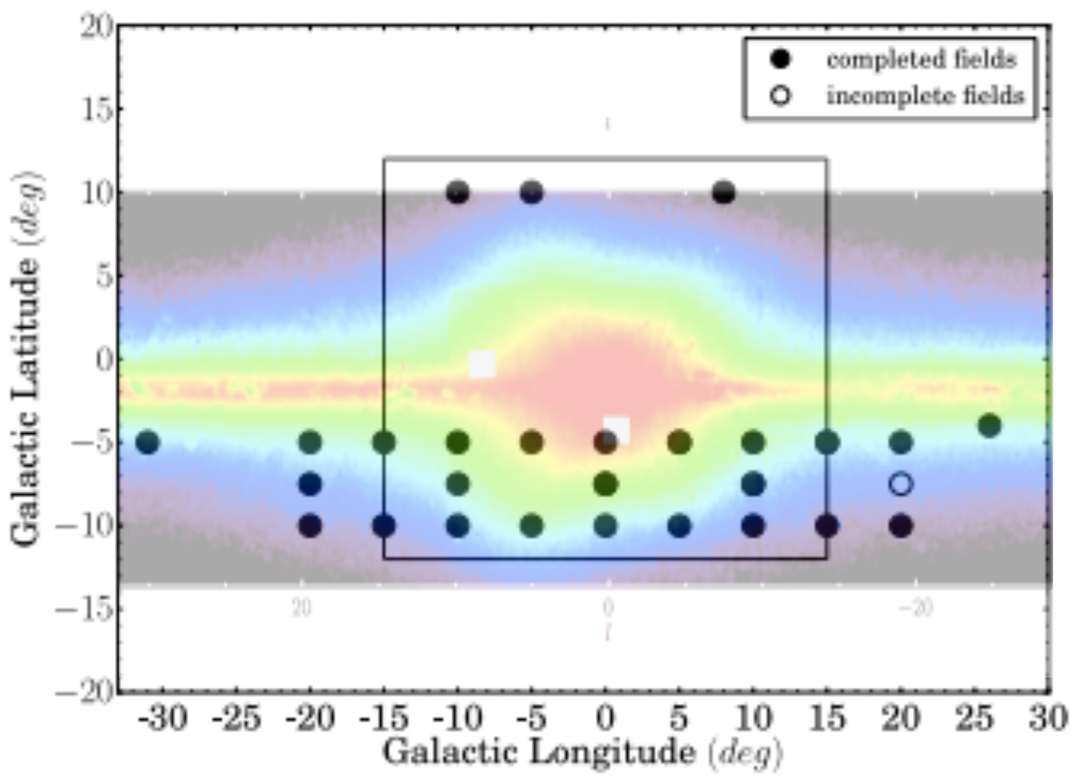
Evidence of cylindrical rotation (i.e.rotation curve independent of the height above the disc)

Shen et al 2010, Kunder et al 2012, Ness et al 2013, Rojas-Arriagada et al 2015

Consistent with a scenario where most of bulge originated in a disc

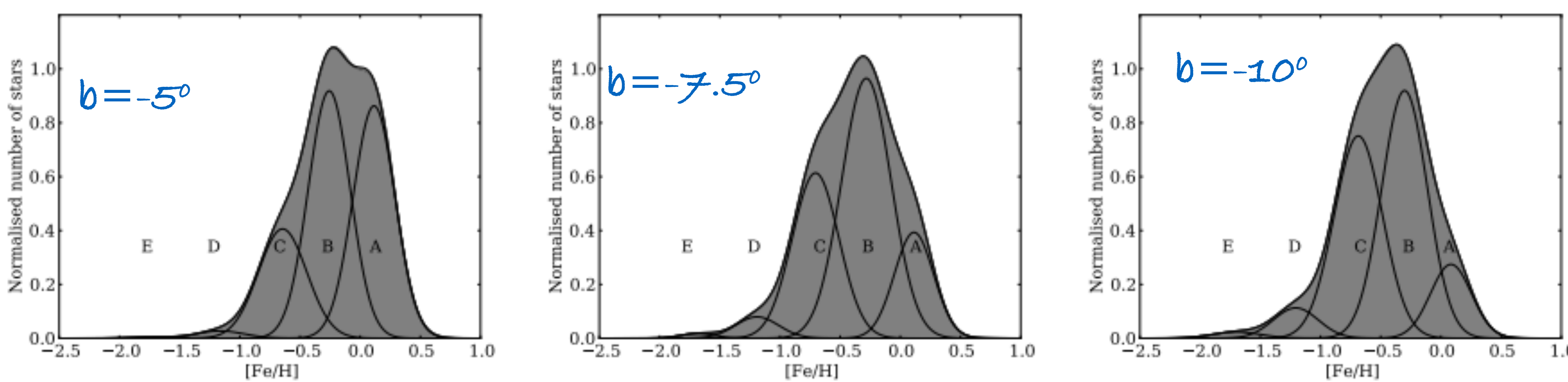
Shen et al 2010, Ness et al 2013, Di Matteo et al 2014

ON THE DISC ORIGIN OF THE MW BULGE



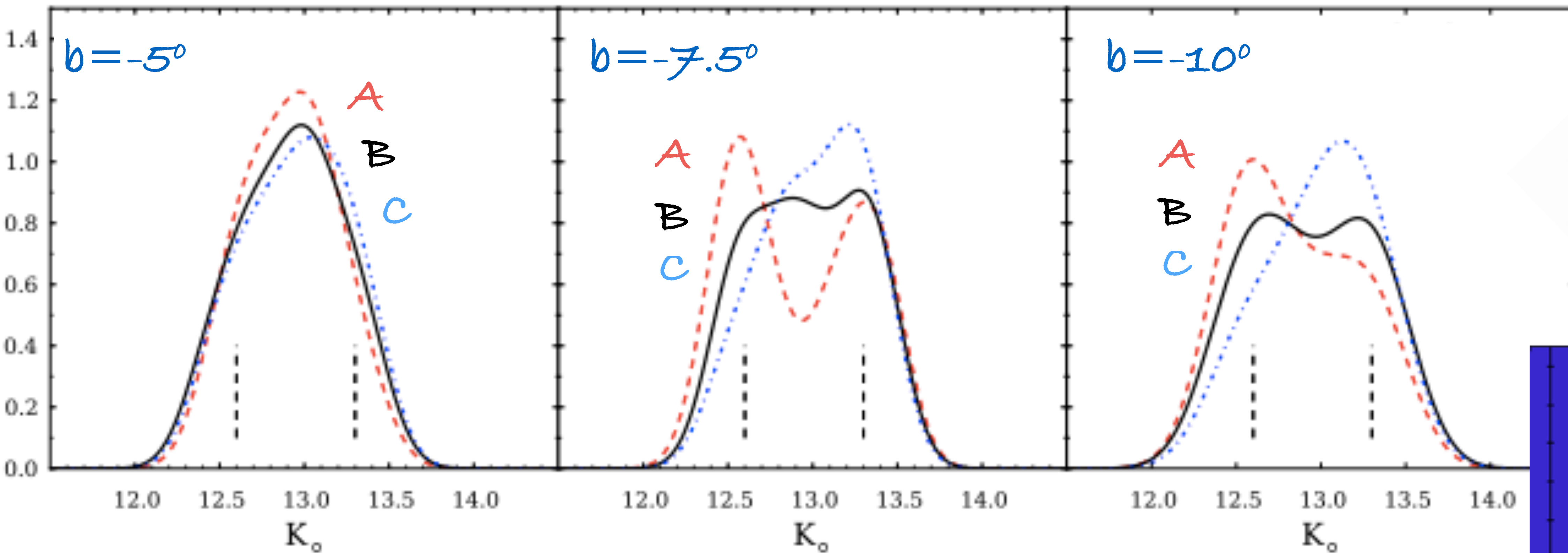
Spectra for 28,000 stars at
a spectral resolution of R = 11,000
(Freeman et al 2012),
AAOmega spectrograph at the Anglo-Australian
Telescope

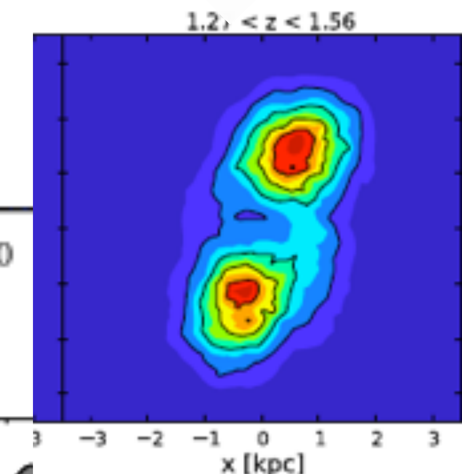
Ness et al 2013

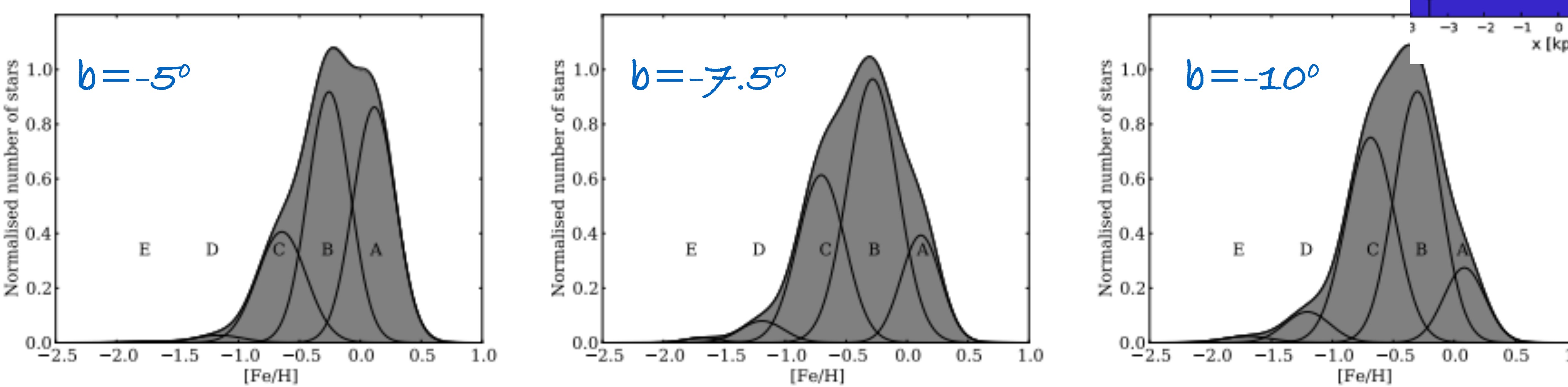


(a) $l \pm 15°, b = -5°$ (b) $l \pm 15°, b = -7.5°$ (c) $l \pm 15°, b = -10°$

ON THE DISC ORIGIN OF THE MW BULGE







(a) $l \pm 15°, b = -5°$

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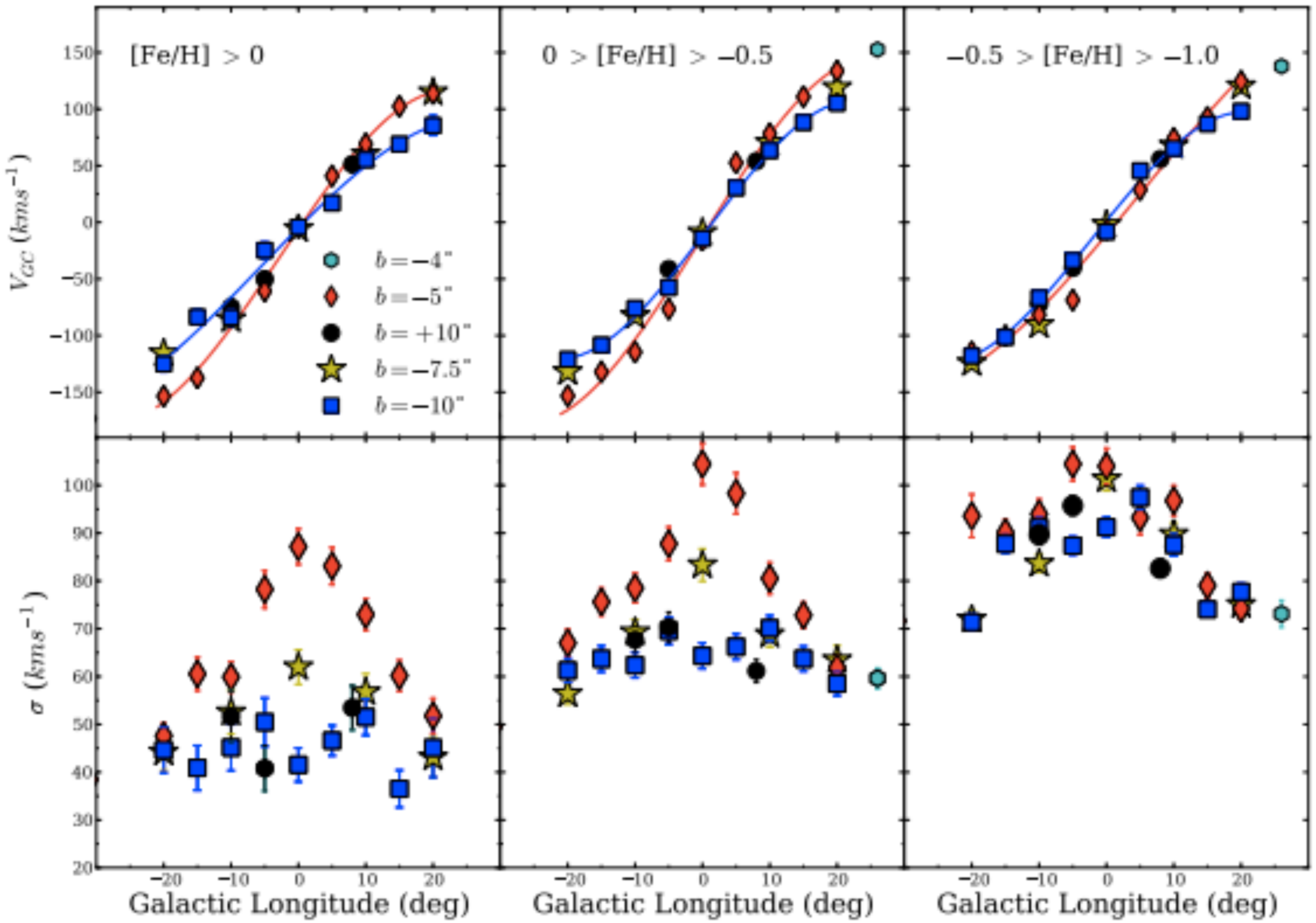
(c) $l \pm 15°, b = -10°$

Ness et al 2013

ON THE DISC ORIGIN OF THE MW BULGE



At all metallicites ([Fe/H]> -1 dex)

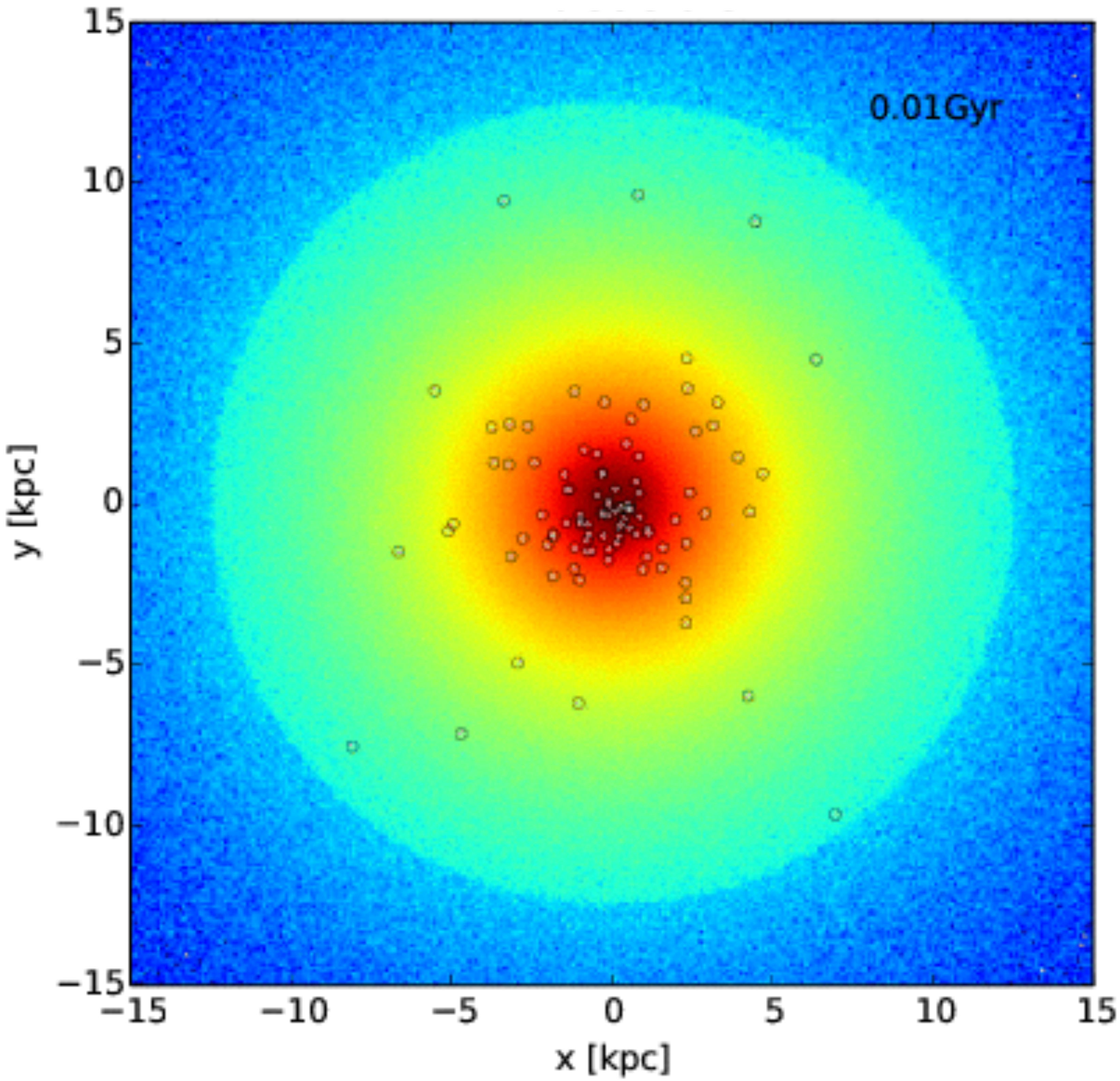
the bulge shows cylindrical rotation

This is a strong signature of the disc origin of the MW bulge

Ness et al 2013

ON THE DISC ORIGIN OF THE MW BULGE

ALL STARS



Disc galaxy evolved in isolation

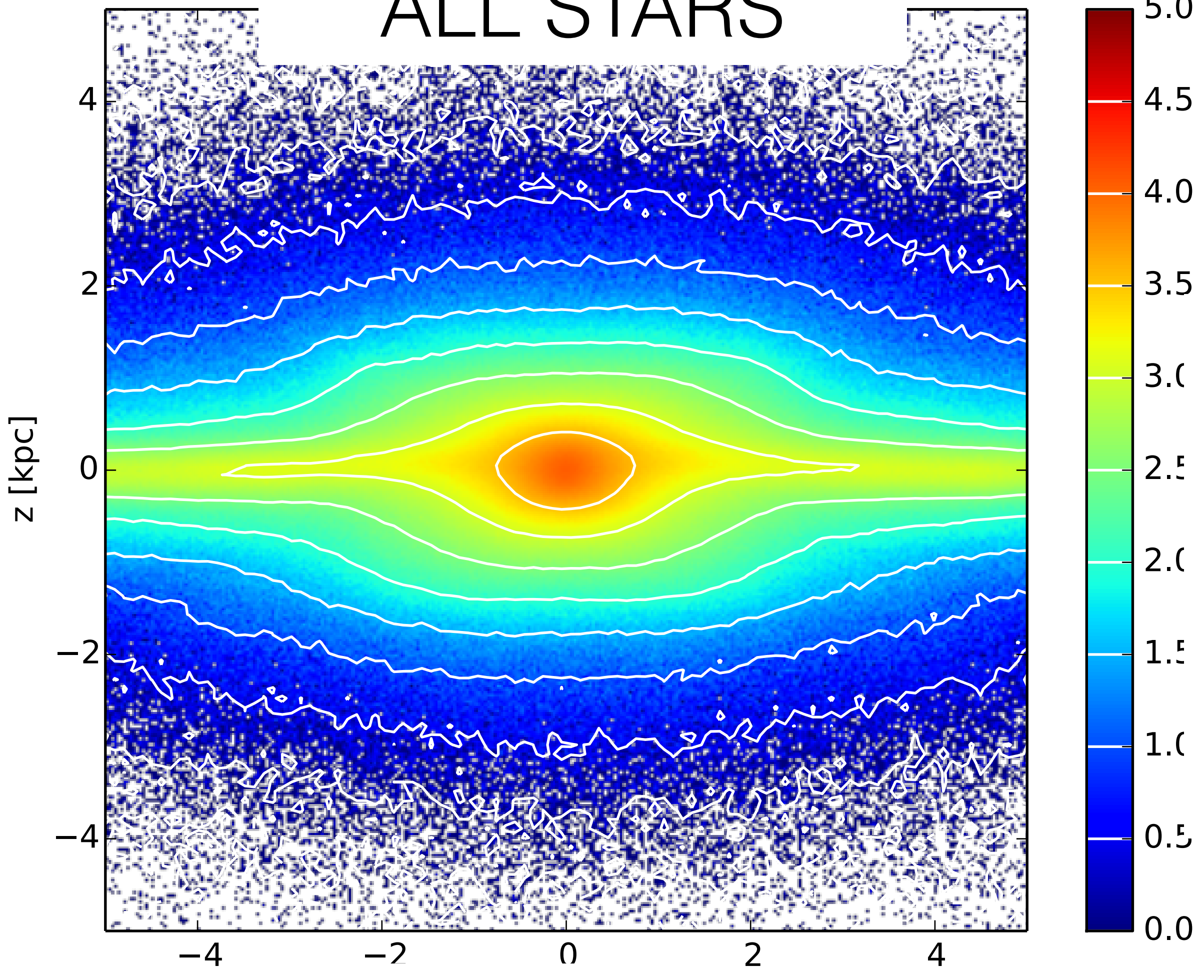
25 000 100 particles (20 000 100 in baryons)
A population of 100 thick disc/bulge globular clusters also simulated

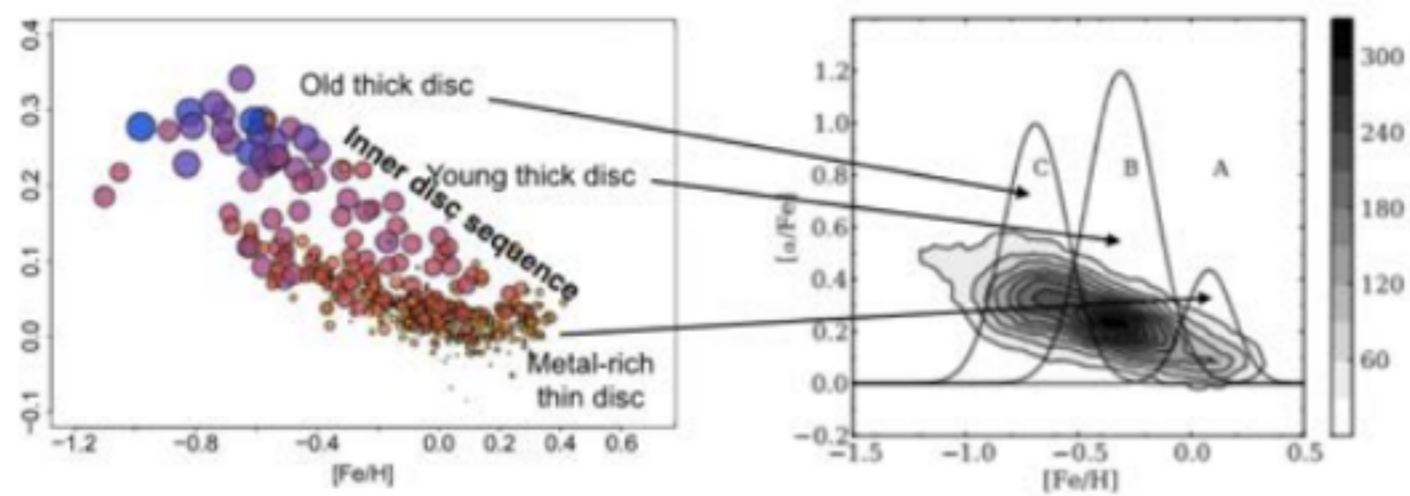
Evolution followed for 5 Gyr

Treecode by Semelin & Combes 2002

ON THE DISC ORIGIN OF THE MW BULGE

ALL STARS

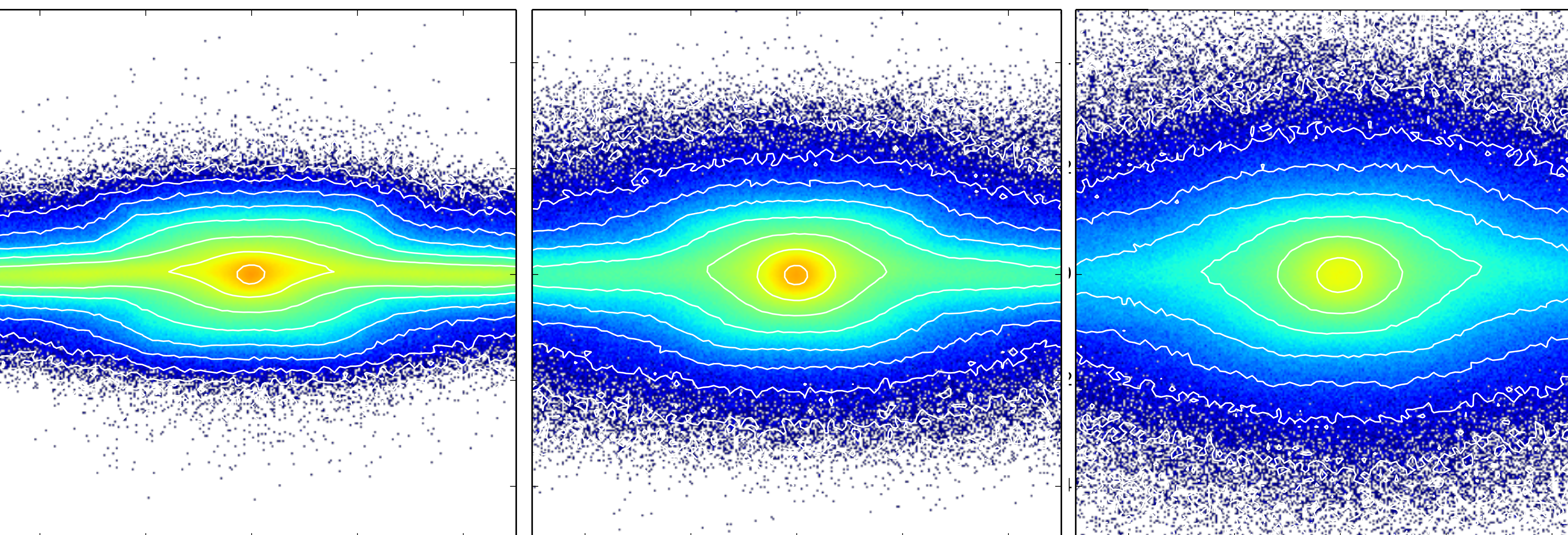




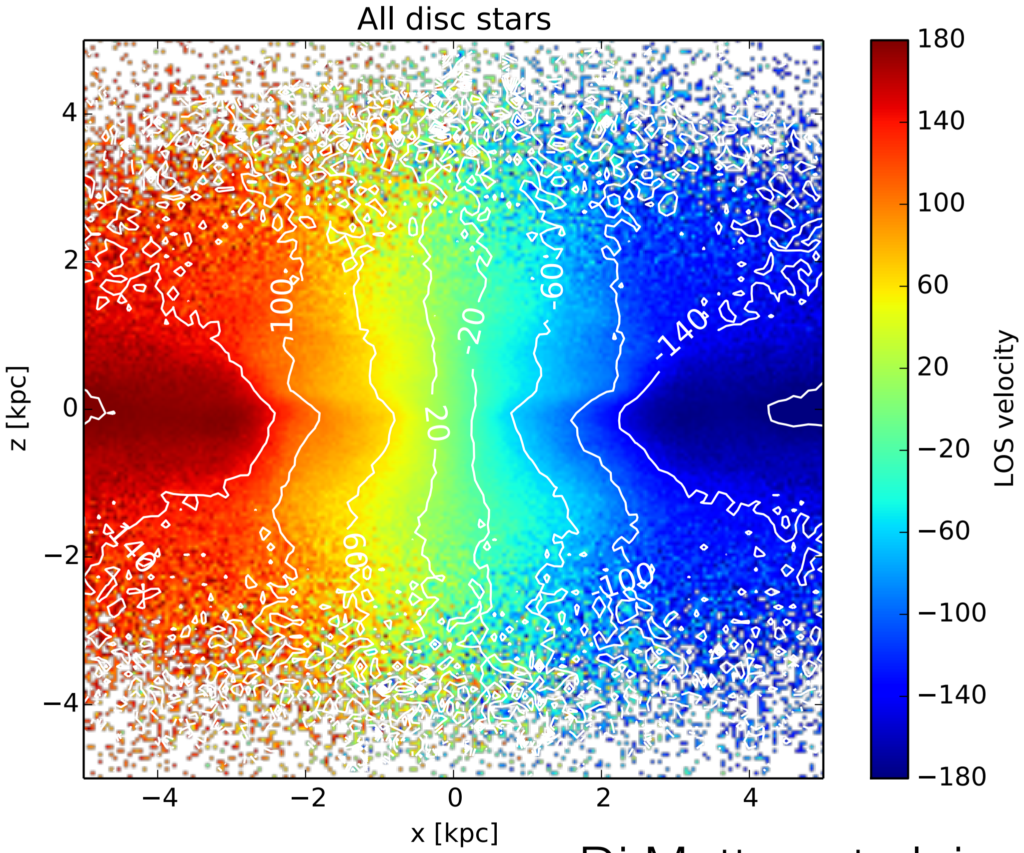
Thin disc

Intermediate disc

Thick disc

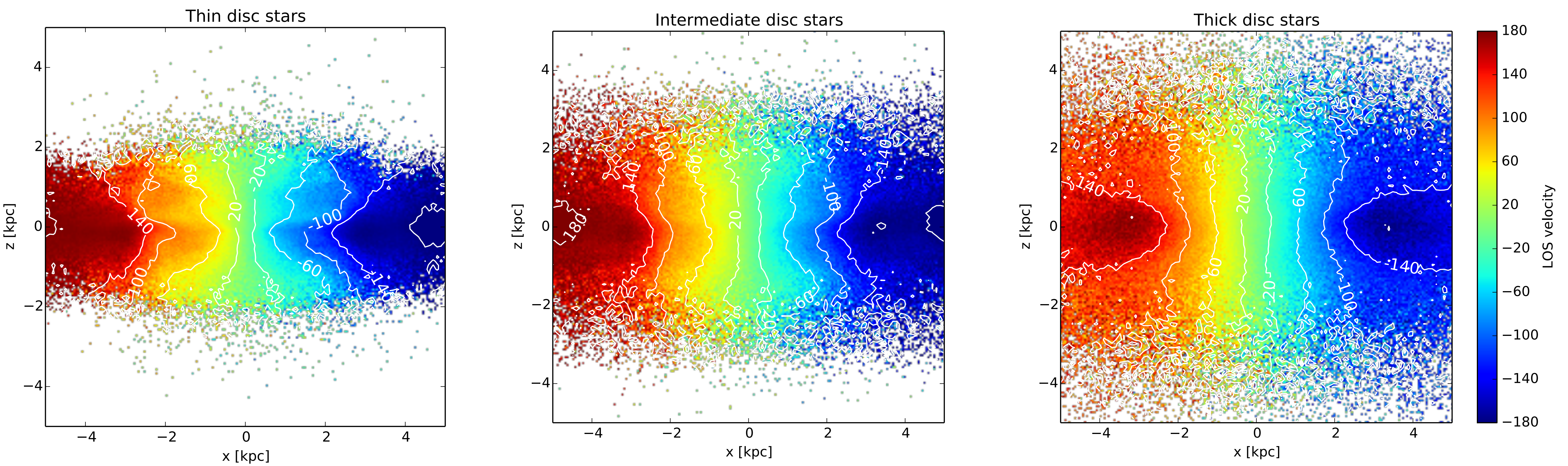


ON THE DISC ORIGIN OF THE MW BULGE



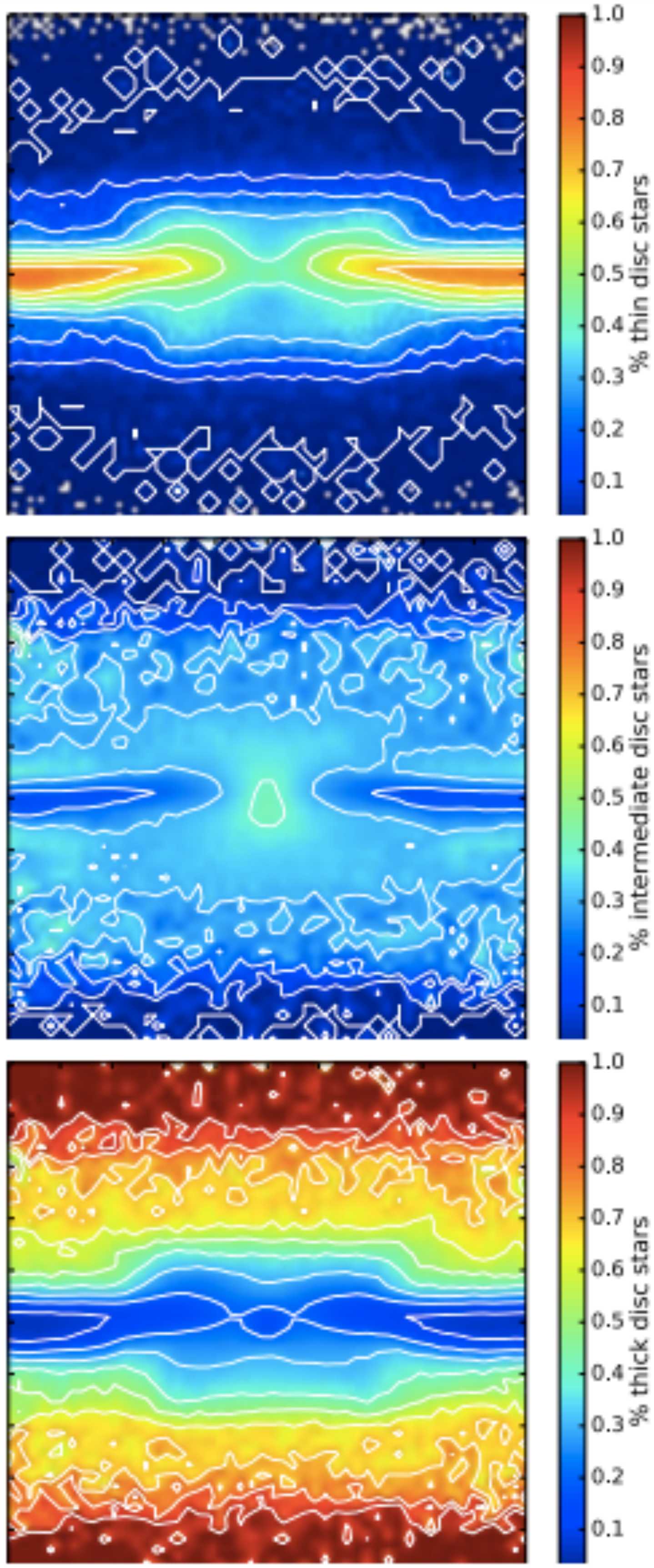
N-body simulations which model the MW bulge as a stellar disc (made of stars with different velocity dispersions) trapped into a bar can reproduce the main kinematic properties observed in the MW bulge :
global cylindrical rotation
cylindrical rotation of its main component, separately

Di Matteo et al, in prep



ON THE DISC ORIGIN OF THE MW BULGE

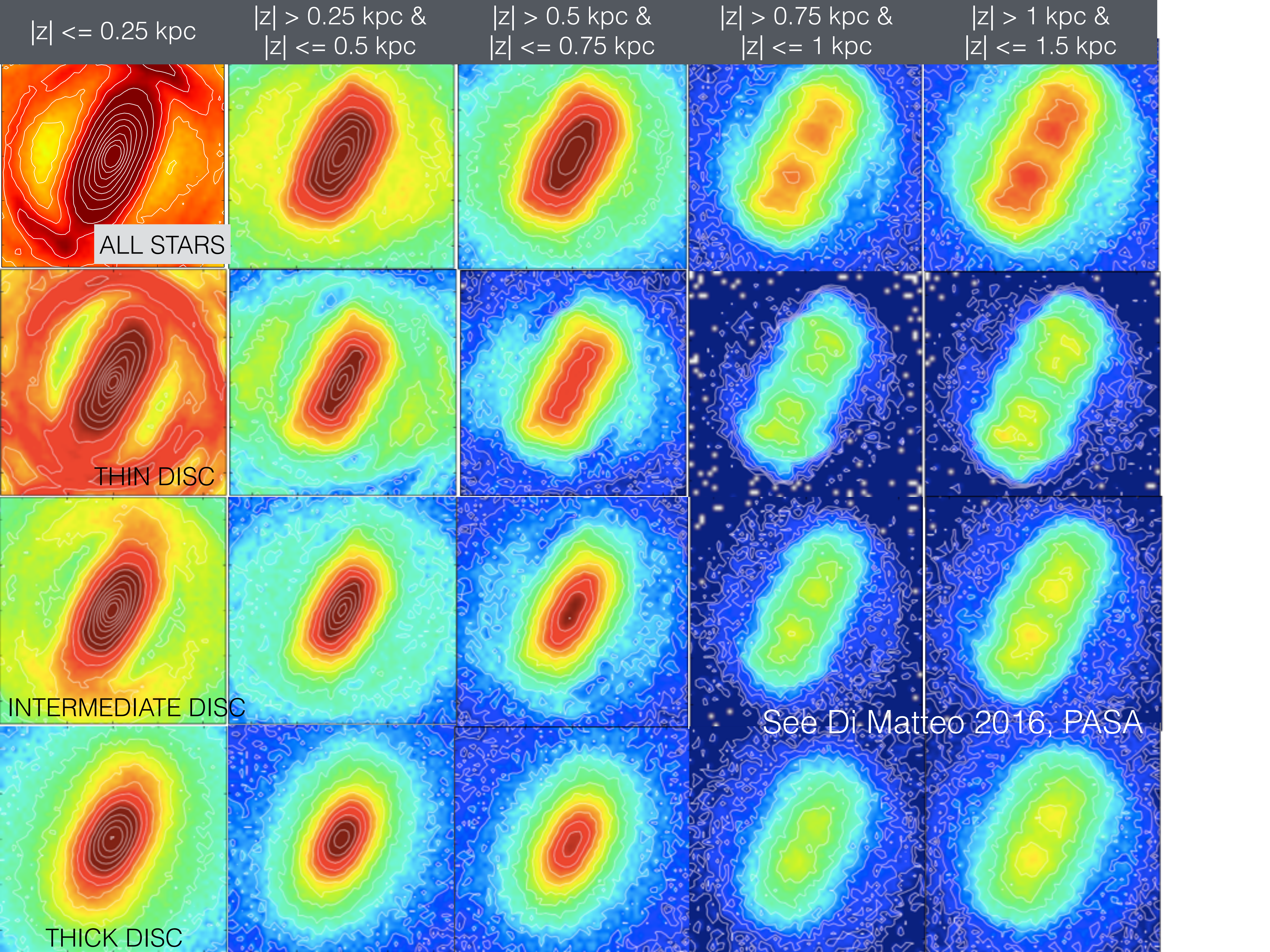
Di Matteo 2016, PASA; Di Matteo+, in prep



By integrating over the whole bulge extent, thin disc stars constitute 40% of the total stellar densities at |z| ≤0.25 kpc, but this fraction diminishes to about 25% at 1. kpc≤ z ≤ 1.5 kpc.

The intermediate disc has a weight which is nearly independent on the vertical distance from the plane : 40% at |z| ≤0.25 kpc, 35% at 1. kpc≤ z ≤ 1.5 kpc.

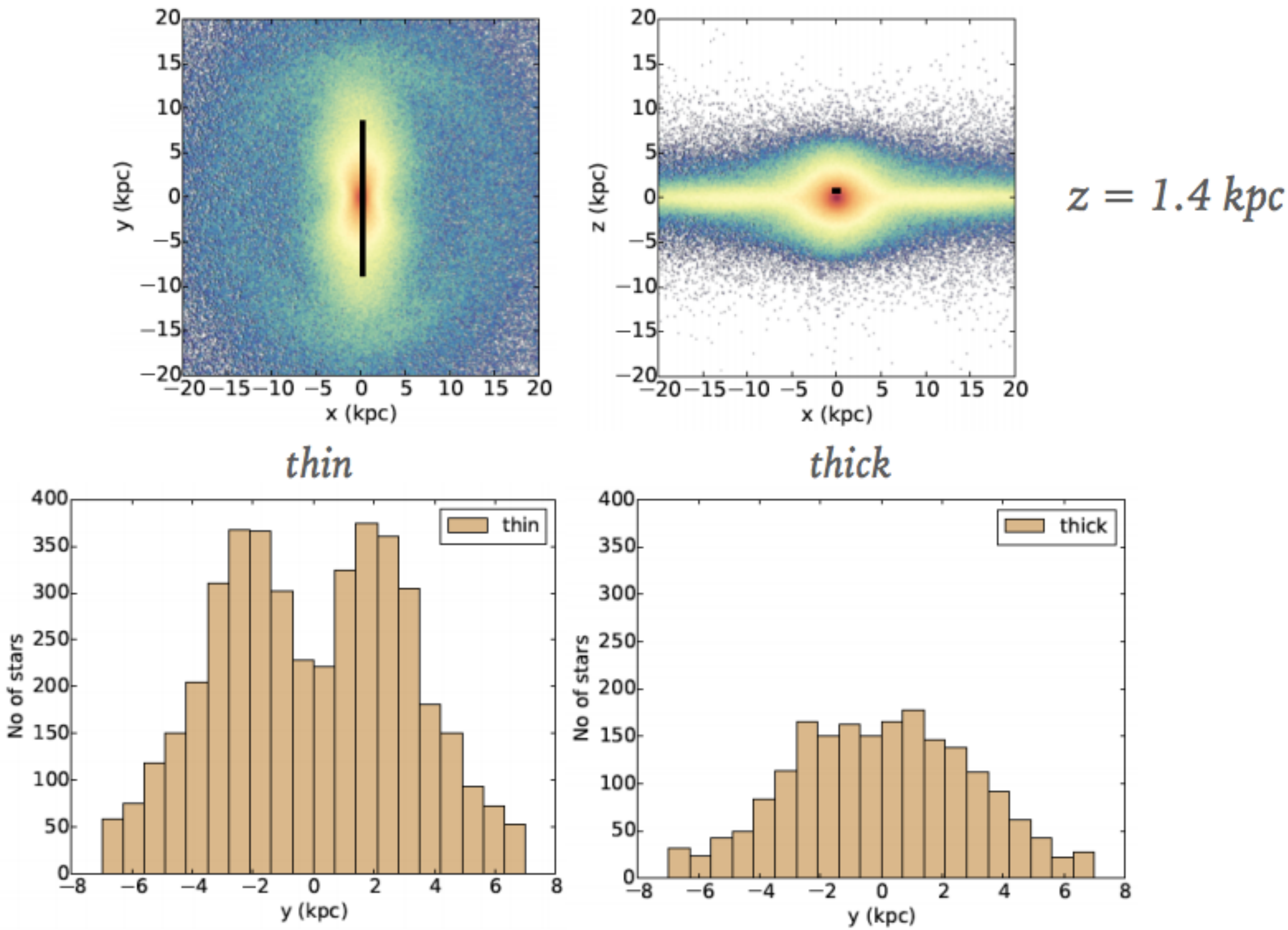
Thick disc stars show the opposite trend : they represent less than 20% of the total stellar density at |z| ≤0.25 kpc, but their fraction rises to more than 40% at 1. kpc≤ z ≤ 1.5 kpc.



|z| <= 0.25 kpc
|z| > 0.25 kpc &
|z| <= 0.5 kpc
|z| > 0.5 kpc &
|z| <= 0.75 kpc
|z| > 0.75 kpc &
|z| <= 1 kpc
|z| > 1 kpc &
|z| <= 1.5 kpc
ALL STARS
THIN DISC
INTERMEDIATE DISC
THICK DISC
See Di Matteo 2016, PASA

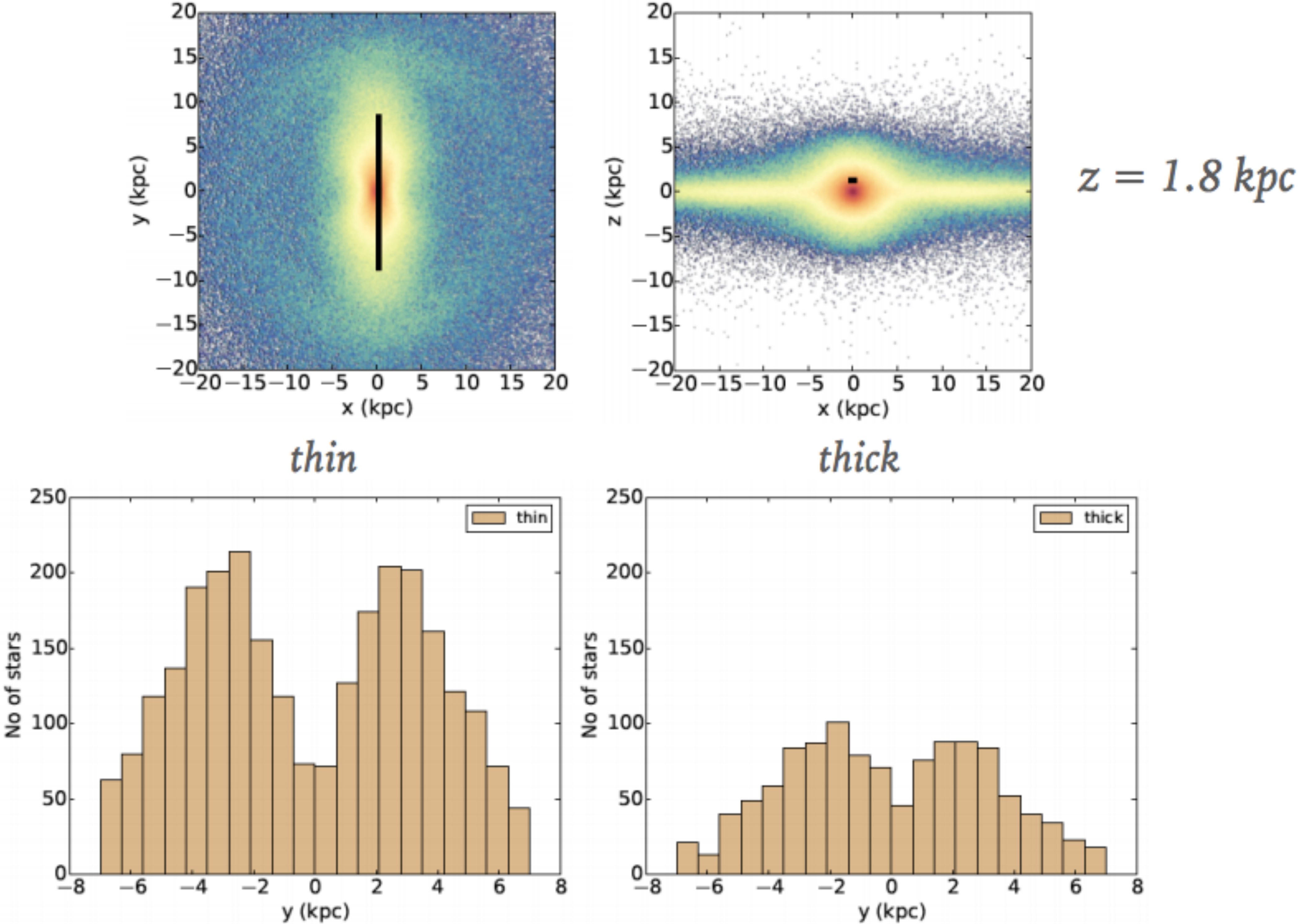
ON THE DISC ORIGIN OF THE MW BULGE

Fragkoudi et al, in prep



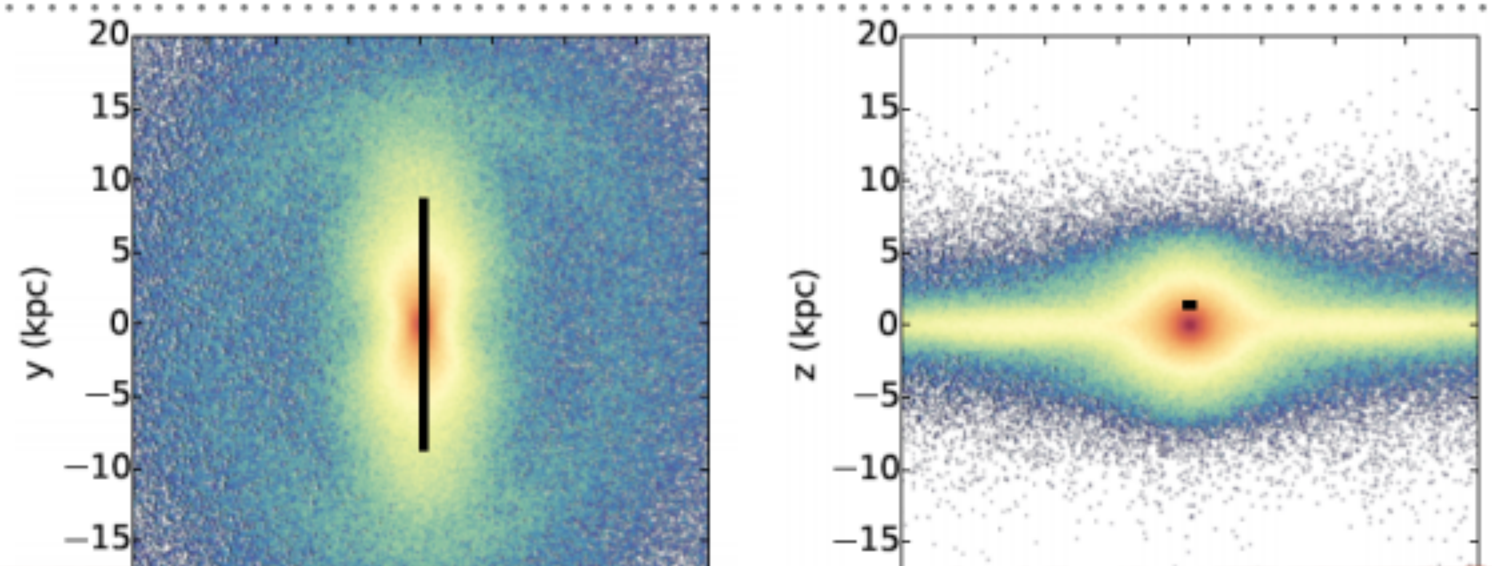
ON THE DISC ORIGIN OF THE MW BULGE

Fragkoudi et al, in prep



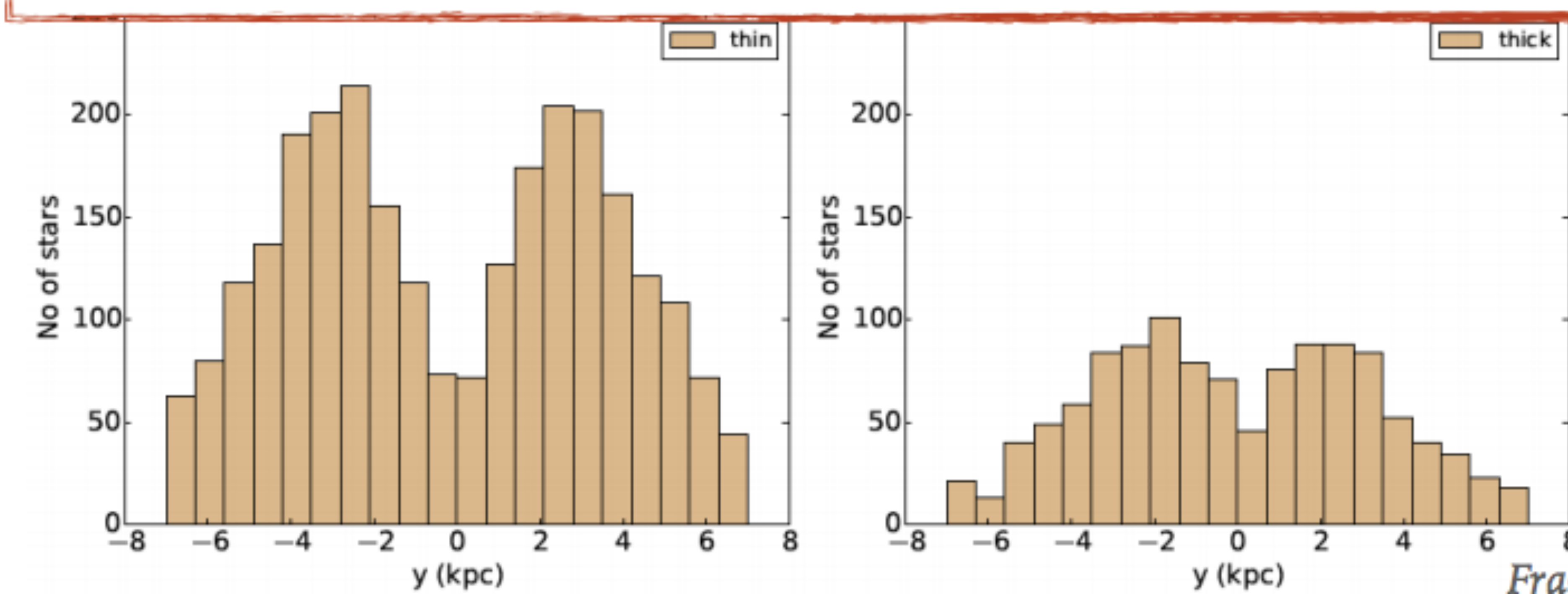
ON THE DISC ORIGIN OF THE MW BULGE

Fragkoudi et al, in prep

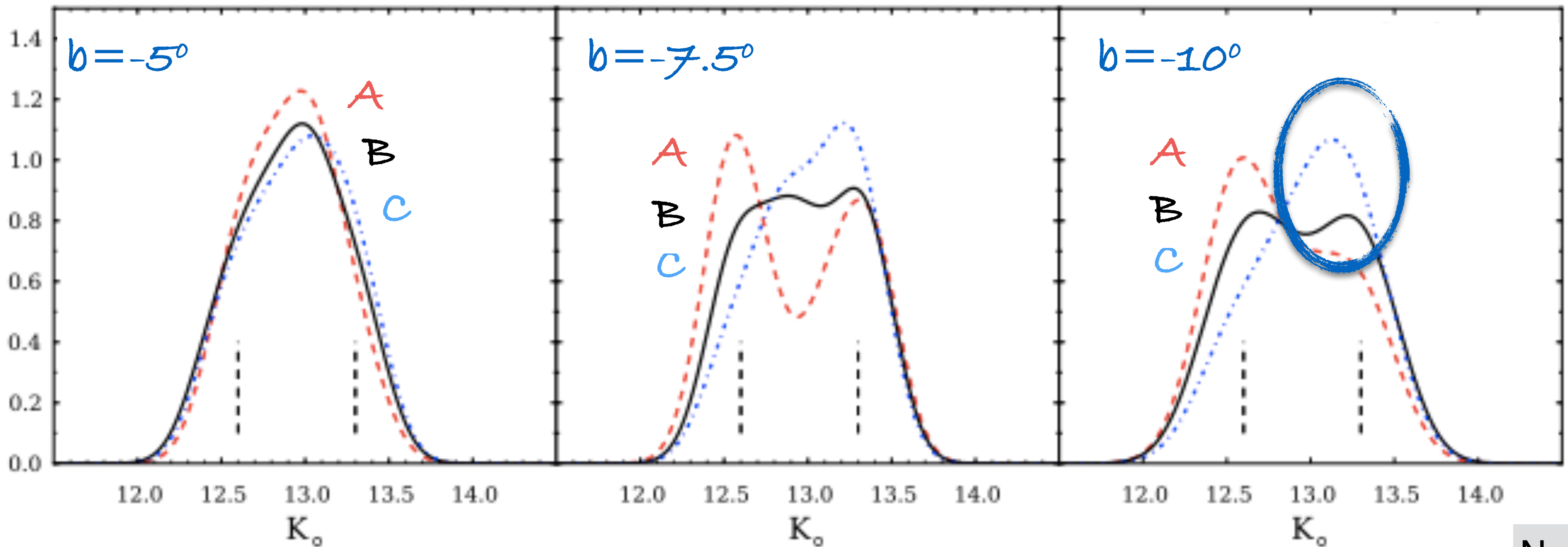


z = 1.8 kpc

Signature of b/p in the thin and thick discs will not necessarily appear at the same latitudes



Fragkoudi+ (in prep)



Ness et al 2013

Hence the necessity to develop a survey that goes beyond |b|=10°, to constrain the **shape and kinematics of the metal-poor bulge component**

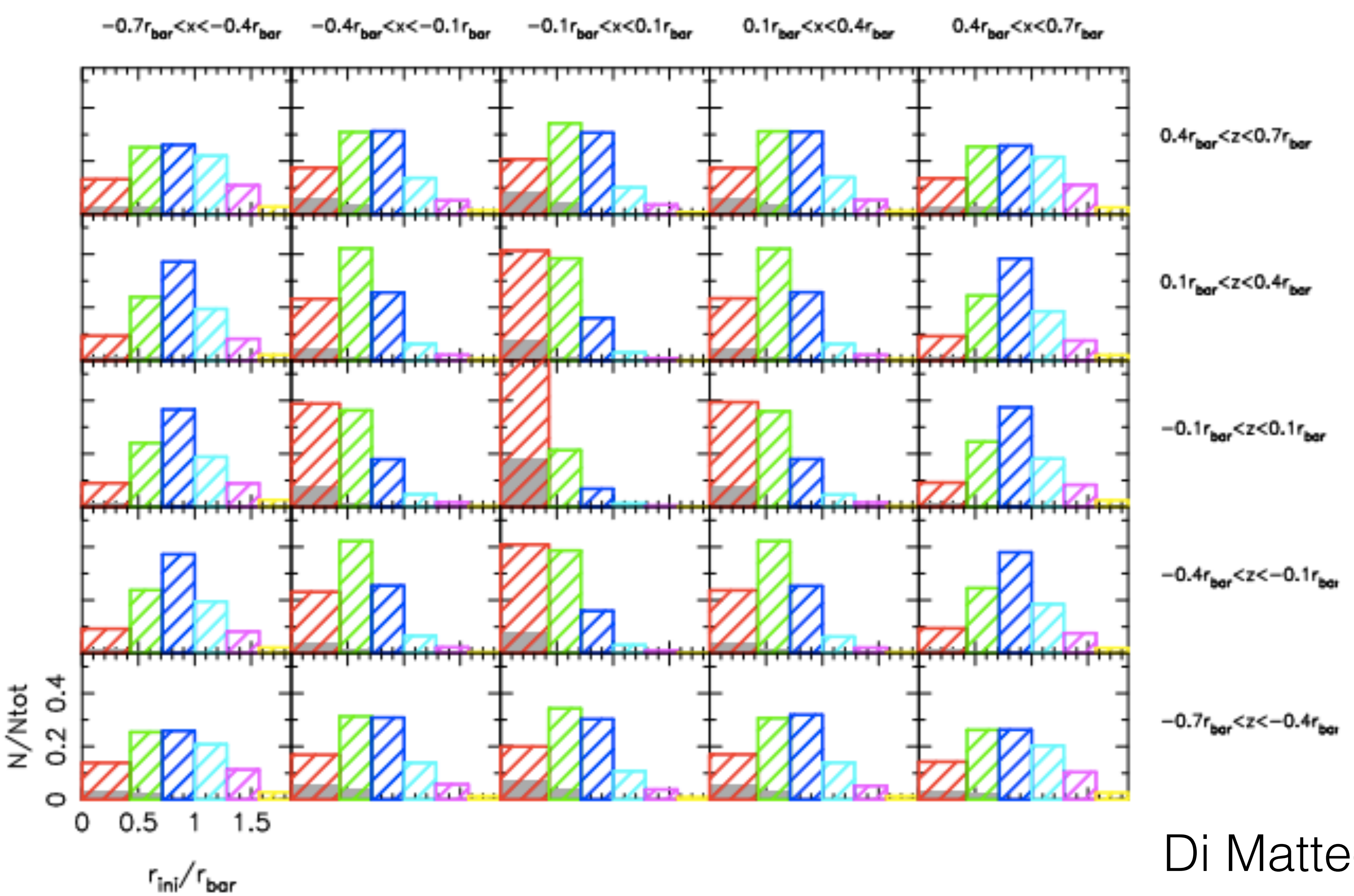
ON THE DISC ORIGIN OF THE MW BULGE

The boxy/peanut-shaped structure of the MW bulge points to a **disc origin** for this structure, with a very limited role of any classical bulge (few % - 10% at most of the disc mass, Shen et al 2010, Kunder et al 2012, Di Matteo et al 2014, Kunder et al 2016).

Which mechanisms (SN feedback ? limited role of mergers ?) **have prevented the Galaxy to form a significant classical bulge ? Absence of significant classical bulges in many galaxies of the local Universe. A challenge for LambdaCDM?** (see Kormendy 2010)

How and where to find the classical bulge of the MW ?

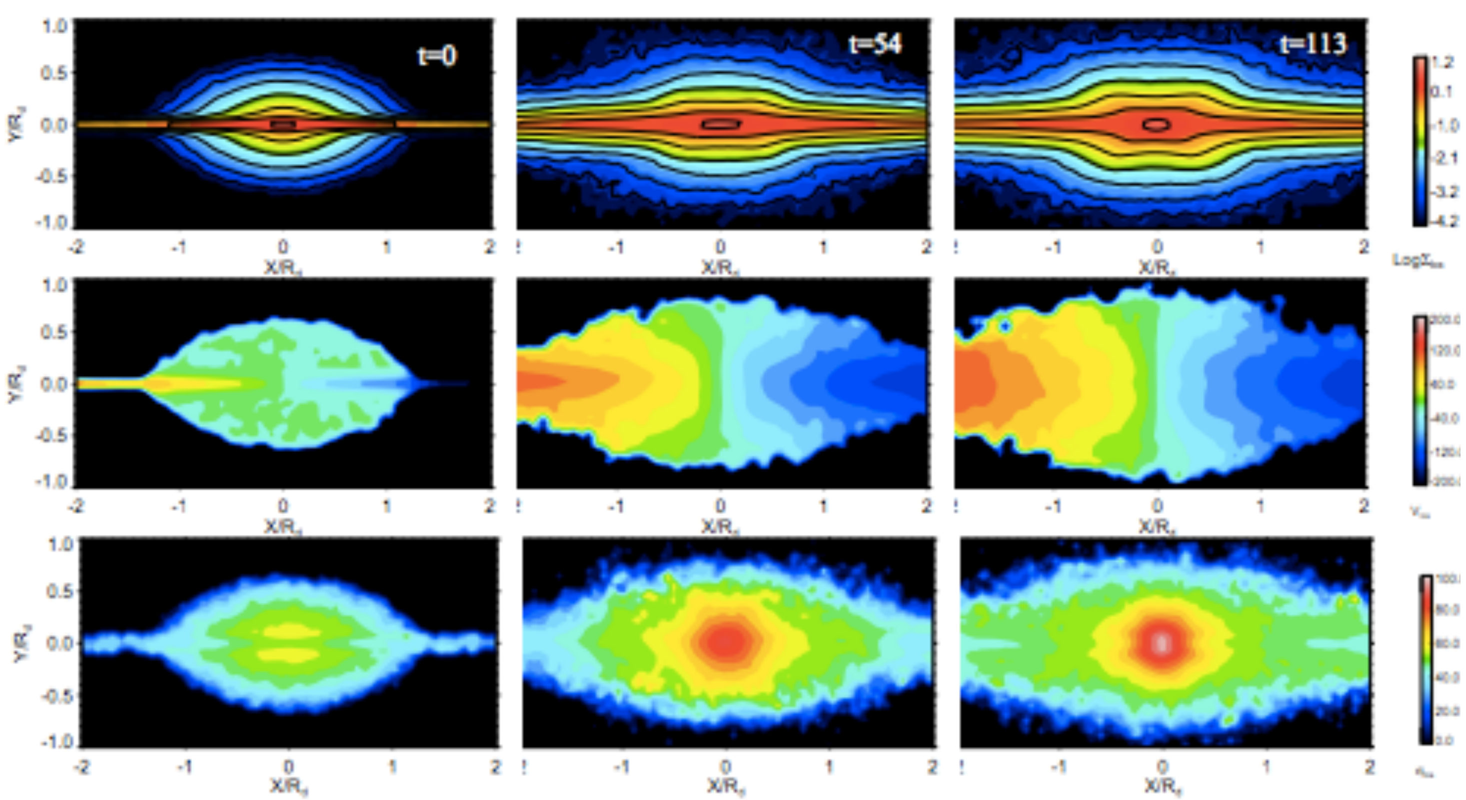
The mass-size relation of spheroids and classical bulges suggests that such a small classical bulge (~ few 10^9 Msun) should have half-mass radii ~ 0.5 kpc. Confined in the innermost regions of the Galactic bulge.



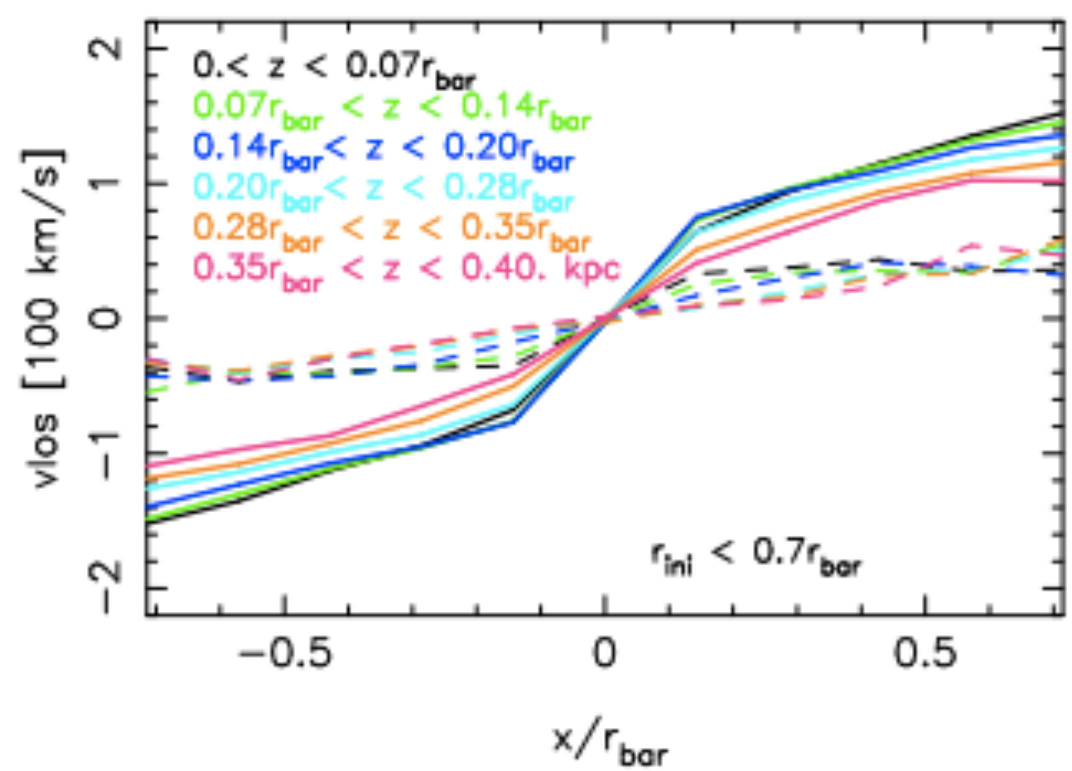
Di Matteo et al 2014

ON THE DISC ORIGIN OF THE MW BULGE

Cylindrical rotation would be expected even in the presence of a small classical bulge (Saha et al 2014, 2015), but **at all longitudes and latitudes the classical bulge is expected to rotate slower than the surrounding disc population**.



Saha et al 2015



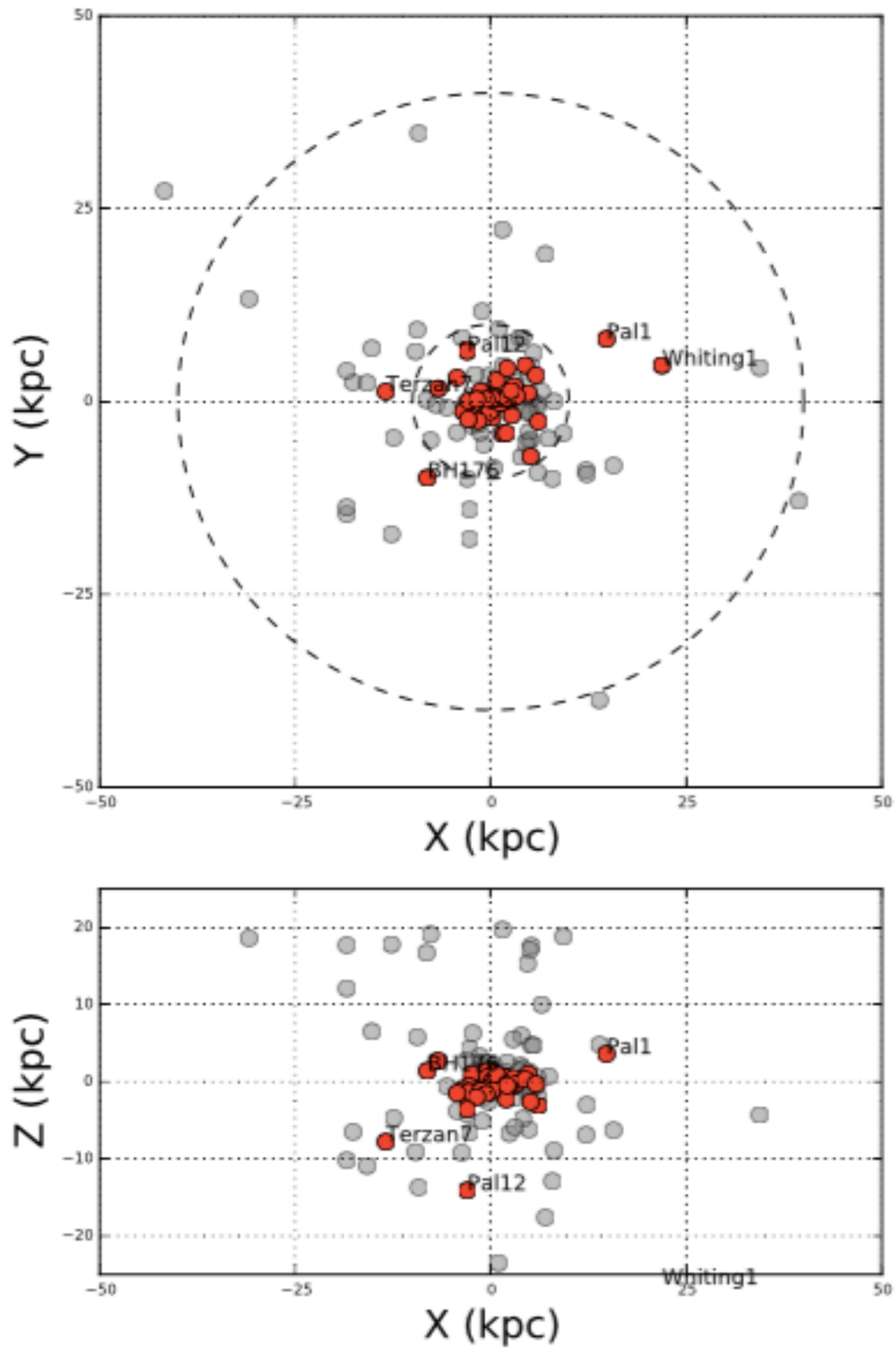
Di Matteo et al 2014

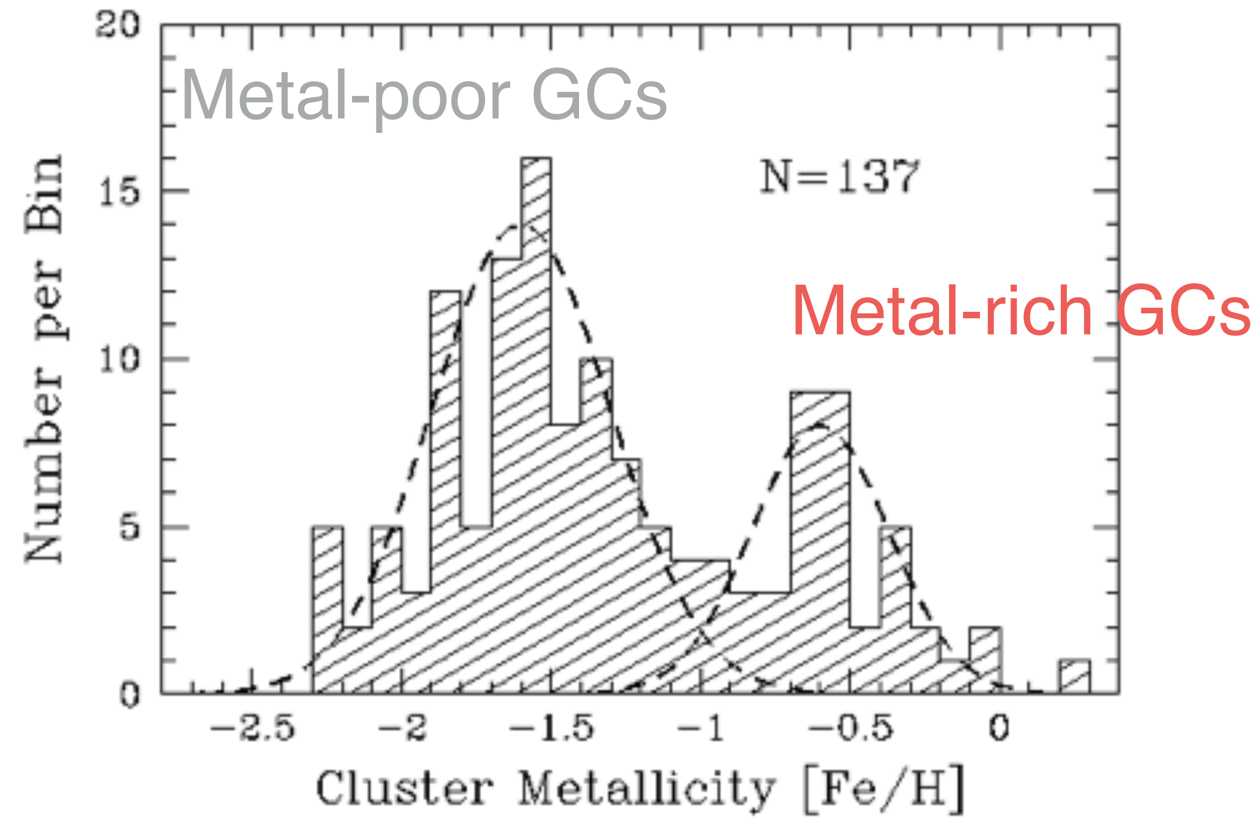
ON THE DISC ORIGIN OF THE MW BULGE

A bulge survey able to penetrate in the obscured regions of the Galactic bulge (close to the plane), and measure radial velocities for ~hundred thousand stars should be able to detect the presence of a hotter component, and estimate its mass.

Chemical abundances coupled to radial velocities would allow to establish if this kinematically hotter component had a star formation history different from that of the surrounding disc.

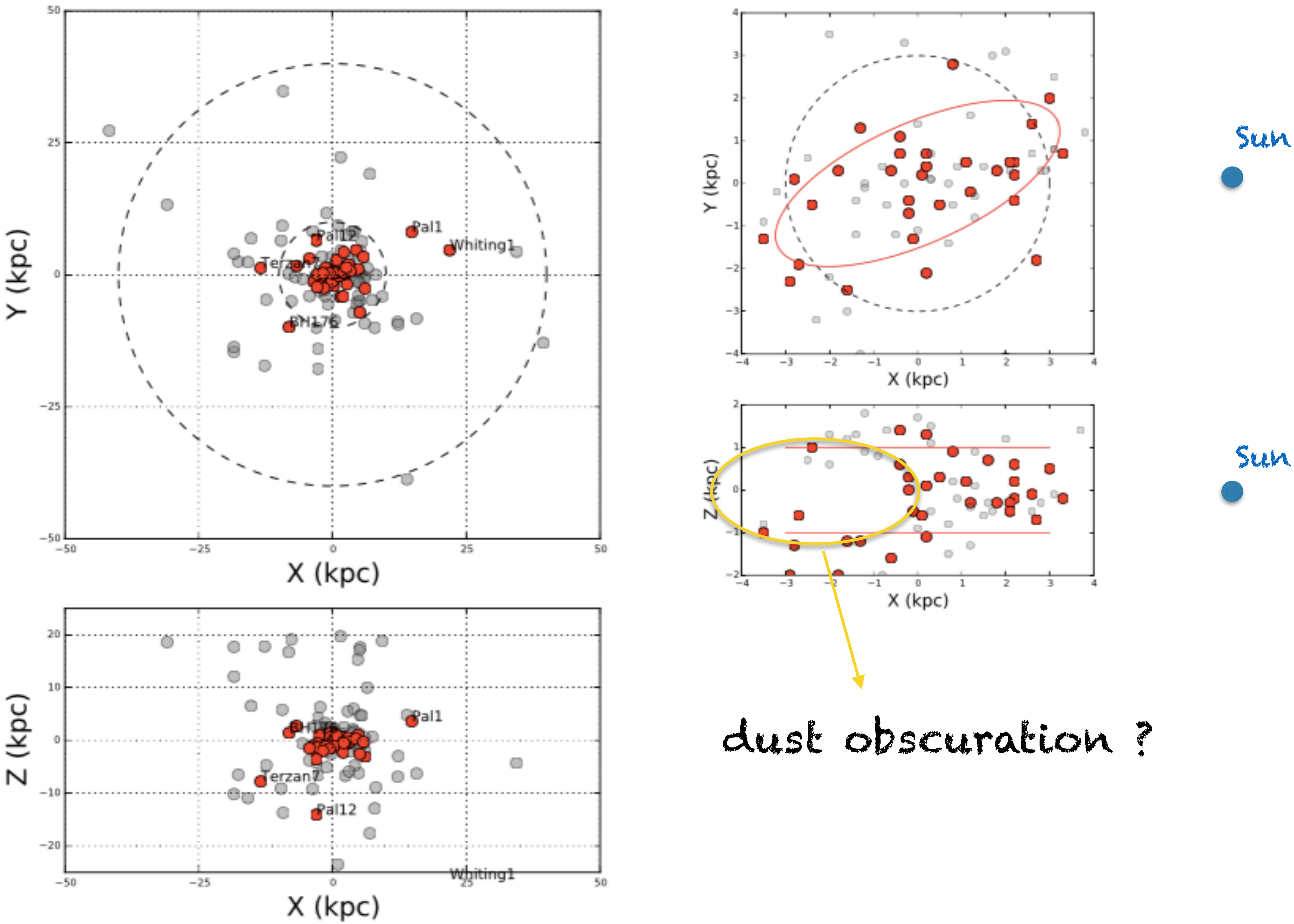
THE GALACTIC GLOBULAR CLUSTER SYSTEM



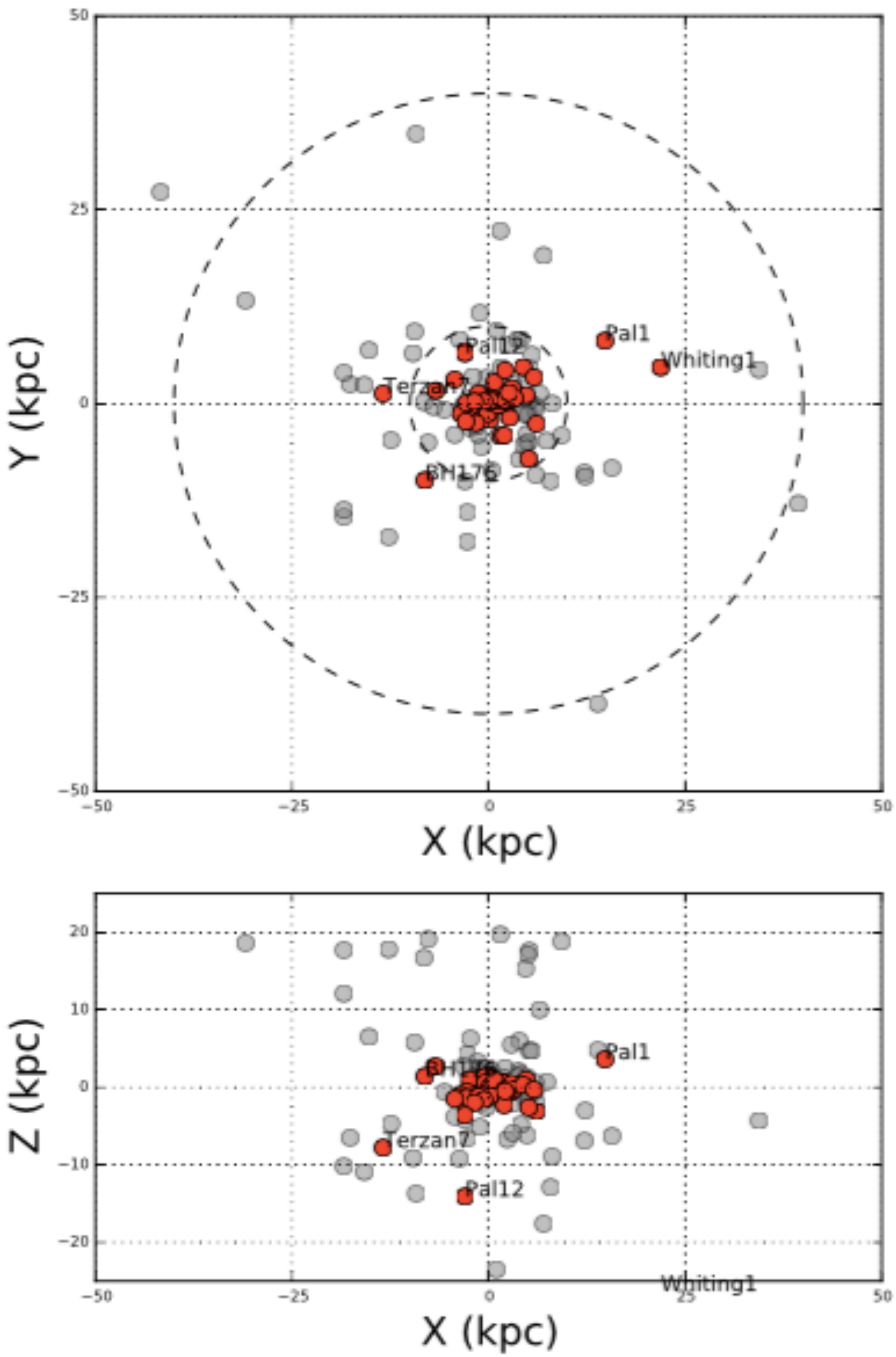


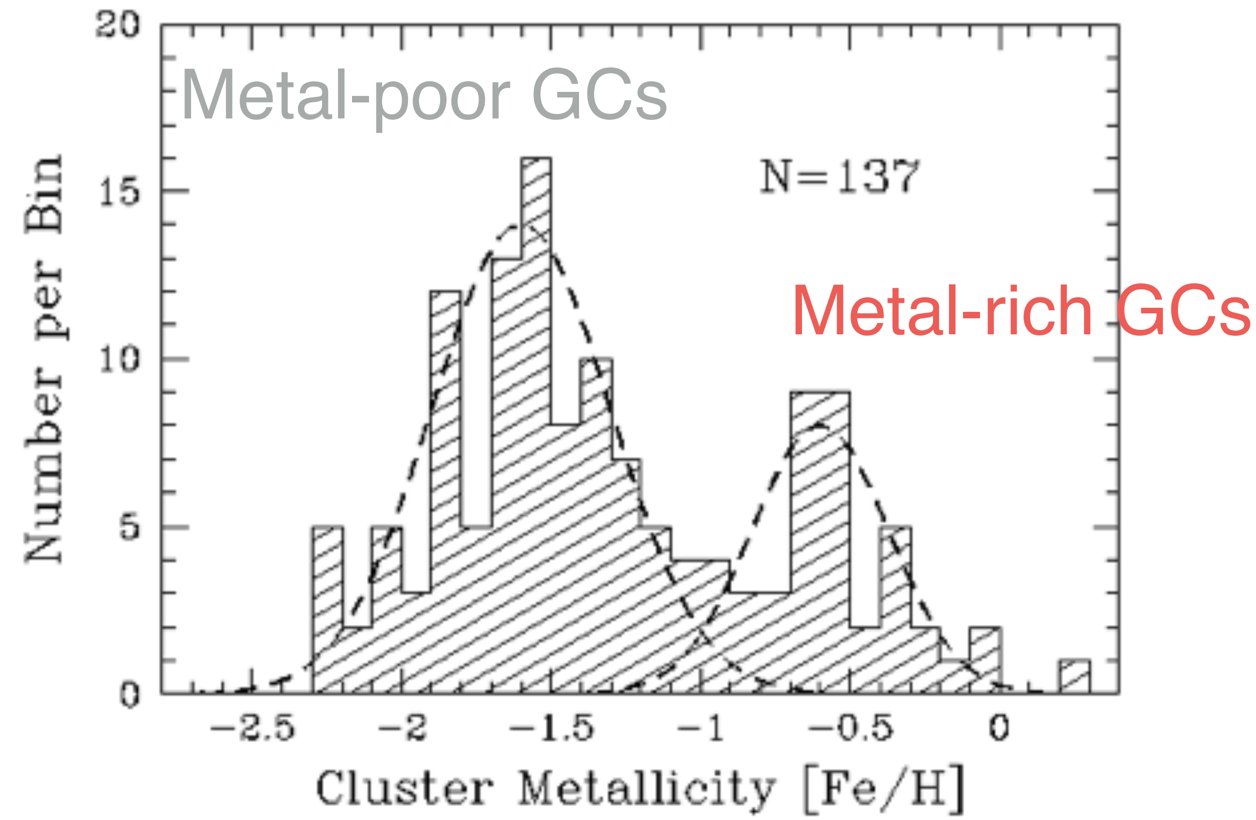
Harris 1999

THE GALACTIC GLOBULAR CLUSTER SYSTEM



THE GALACTIC GLOBULAR CLUSTER SYSTEM





Harris 1999

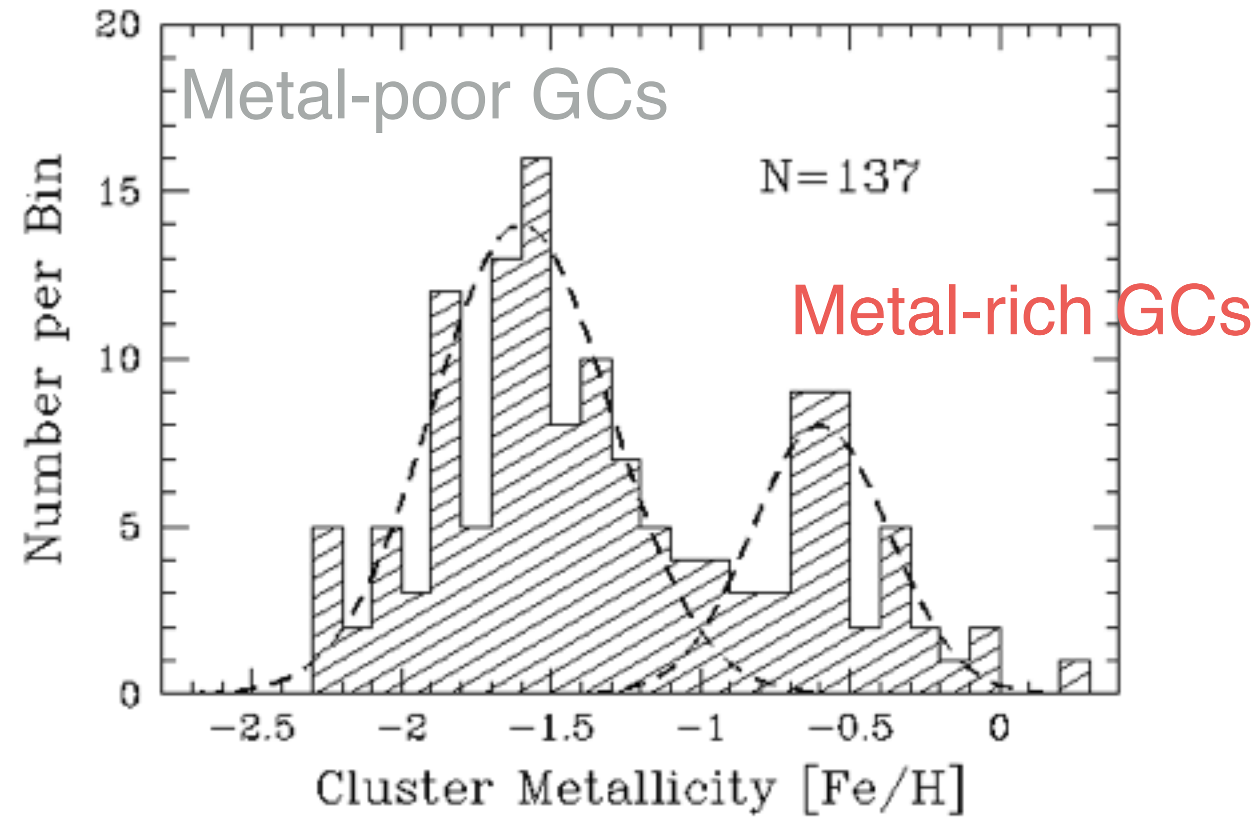
How many GCs are still unobserved in the inner kpc of the Galaxy ?

What is the real metal-rich/metal-poor GC ratio in the Galaxy ?

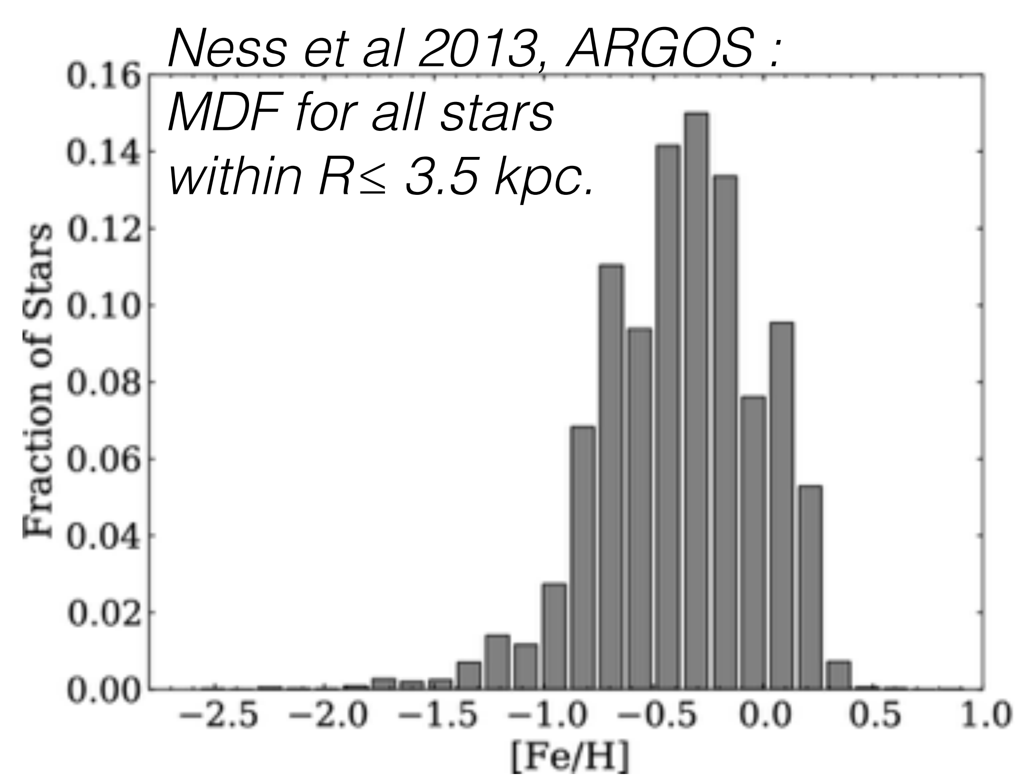
What is the initial MDF of the GC system ?

Why is the MDF of the Galactic GC system so different from that of field stars ?

Among field stars :
~10% have [Fe/H] ≤ -1 dex.
Among the GC population :
~60-70% have [Fe/H] ≤ -1 dex.
Most of the GC system has [Fe/H] ≤ -1 dex, while the large majority of field stars has [Fe/H] > -1 dex.



Harris 1999



Did the most favorable epoch of GC formation in the Galaxy coincide with the formation of the stellar halo ([Fe/H] ≤ -1 dex) ?

Is most of the metal-poor GC population accreted, i.e. not formed in-situ ?

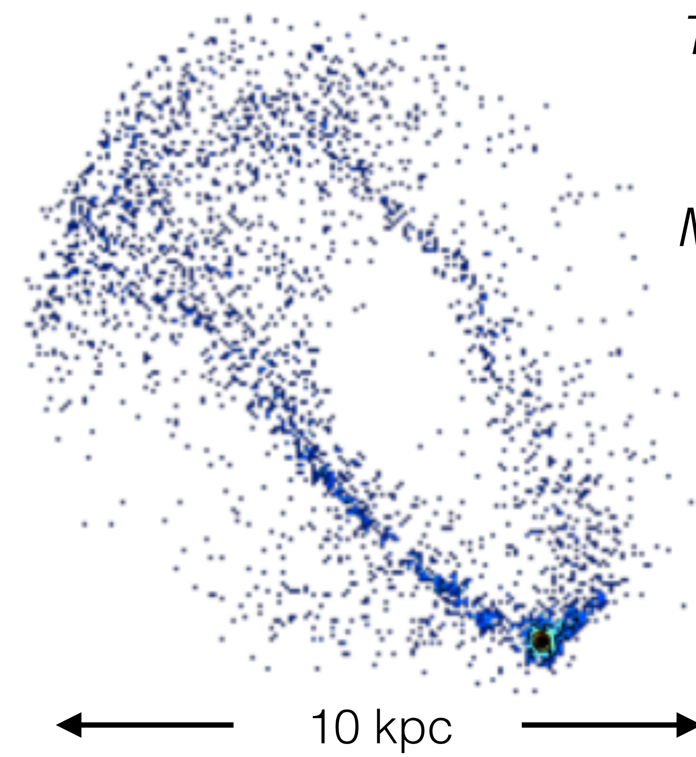
Did the GC system experience a metallicity-dependent tidal destruction, with metal-rich GCs more favorably destroyed than metal-poor ones ?

THE GALACTIC GLOBULAR CLUSTER SYSTEM

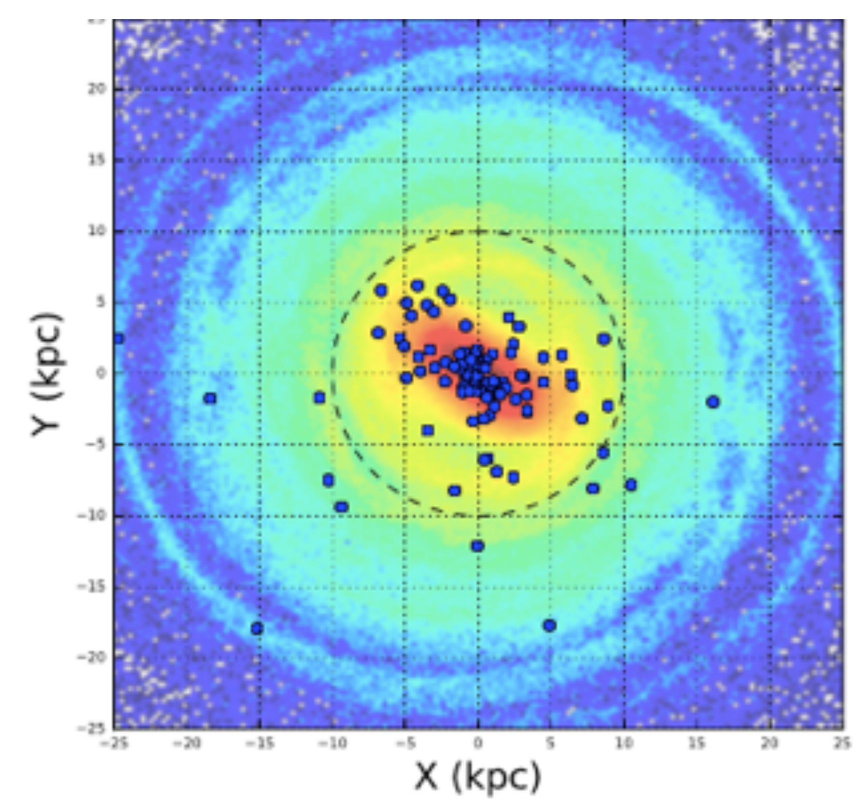
Jean-Baptiste et al, in prep :
The metal-rich GC population is associated to the thick disc, as already suggested some decades ago by Zinn (1985) and Armandroff (1989) but questioned by Minniti (1995).

The thick disc, as the metal-rich GC population, has a short scale length : strongly concentrated in the inner kpc of the Galaxy, where **tidal effects can have severely reduced the initial population of disc GCs,** by destroying a large number of them.

The MW stellar bar can also play a role, by increasing the eccentricities of disc GCs, and focus their orbits in the very inner kpc of the MW.

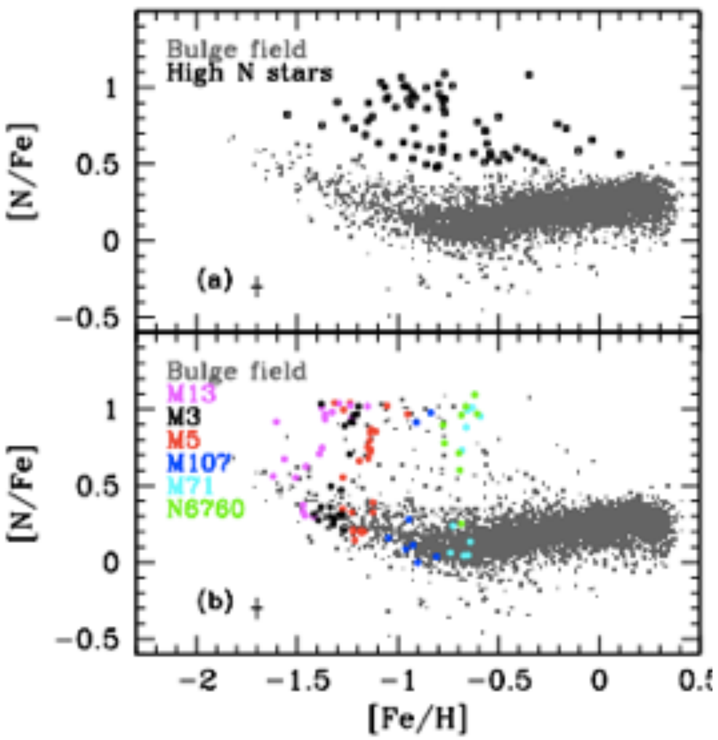


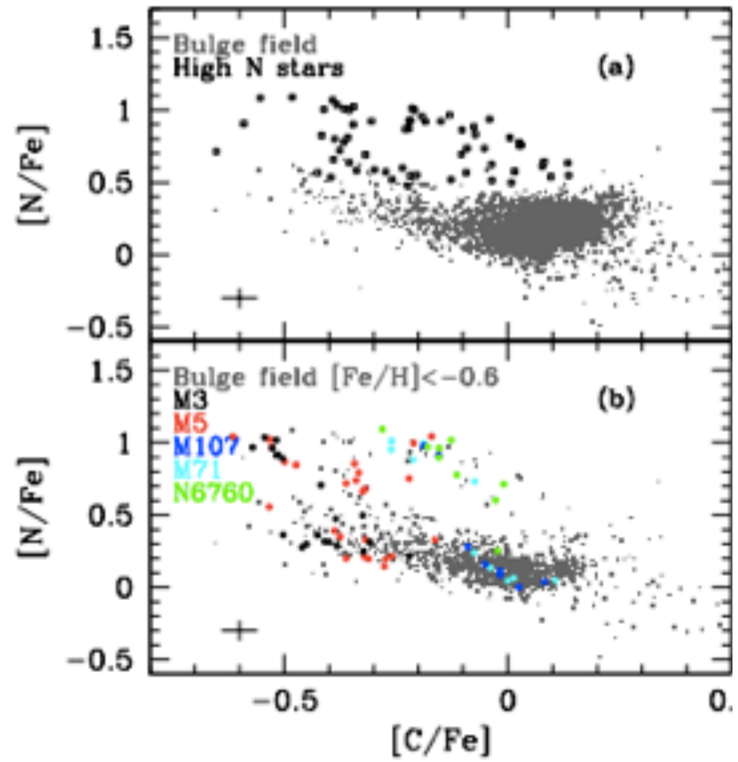
Thick disc GC in the galactic tidal field - simulations by A. Mastrobuono-Battisti

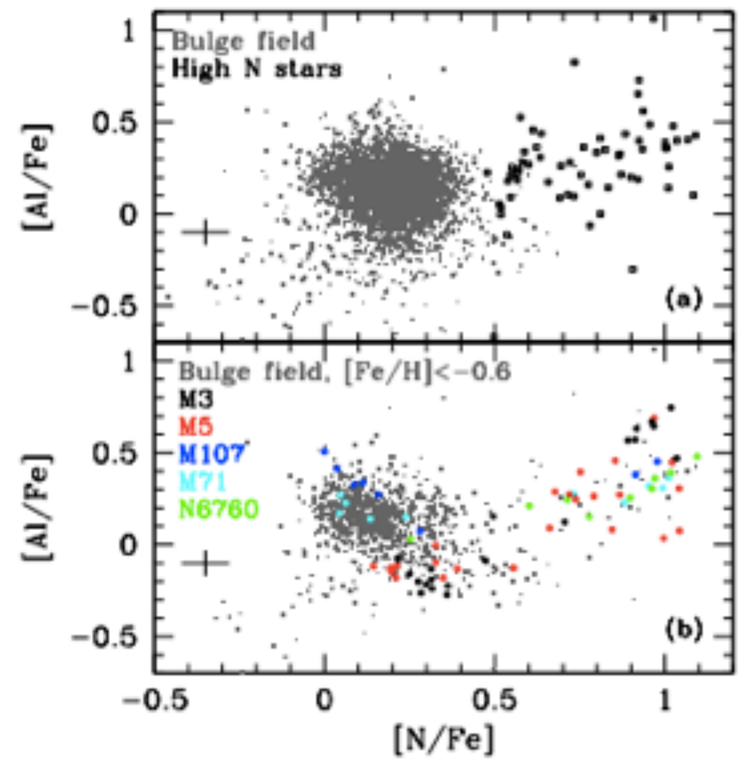


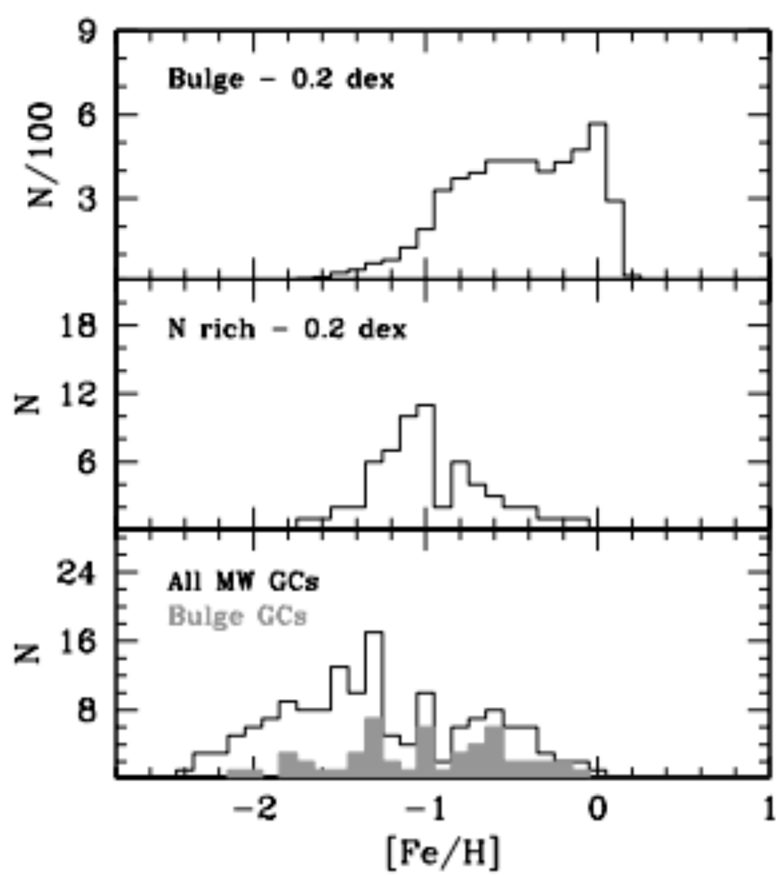
I. Jean-Baptiste, PhD thesis

THE GALACTIC GLOBULAR CLUSTER SYSTEM









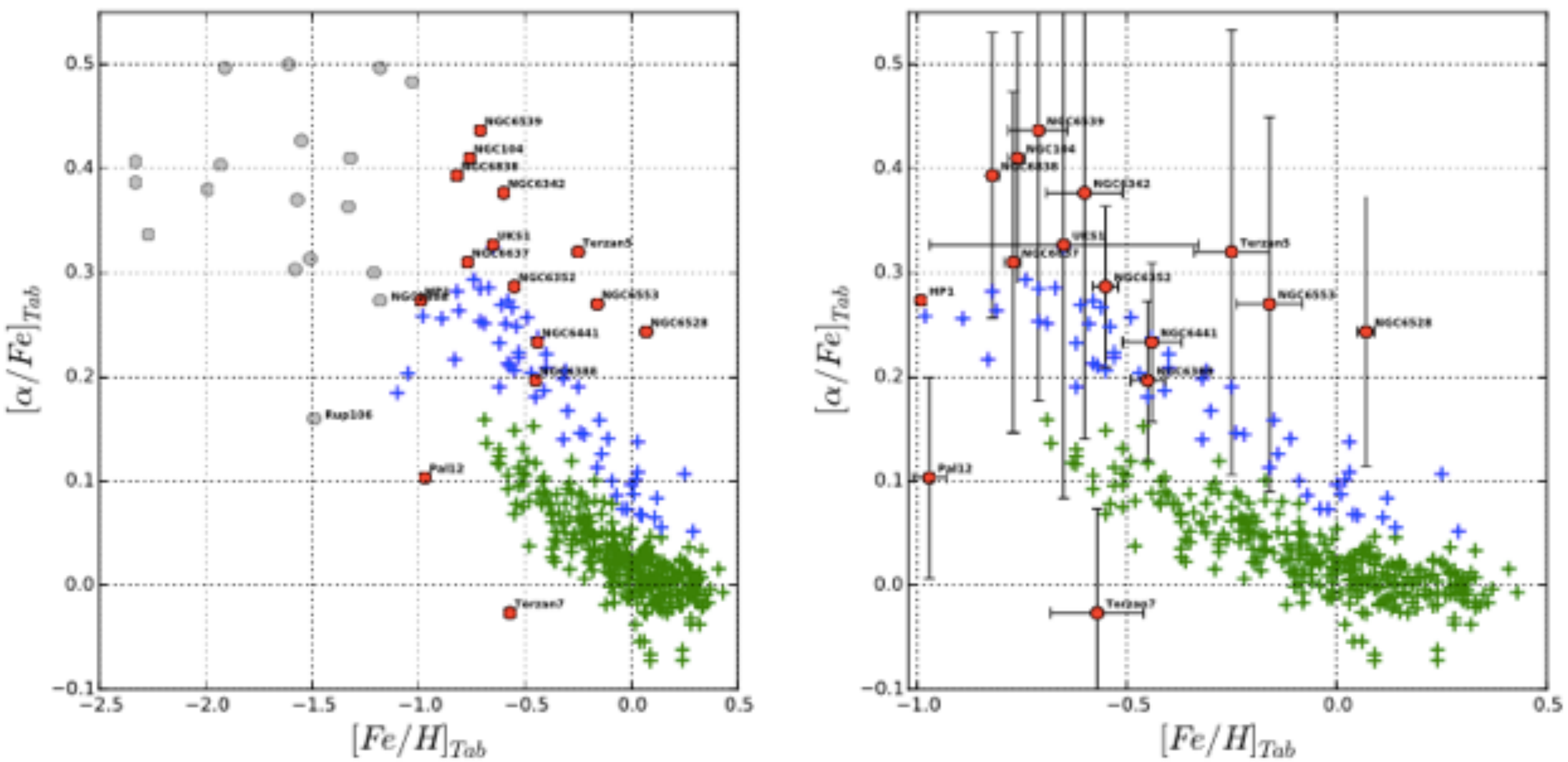
Schiavon et al, 2016, APOGEE

N-rich stars could be former members of dissolved GCs, in which case the mass in destroyed GCs exceeds that of the surviving GC system by a factor of ~8.

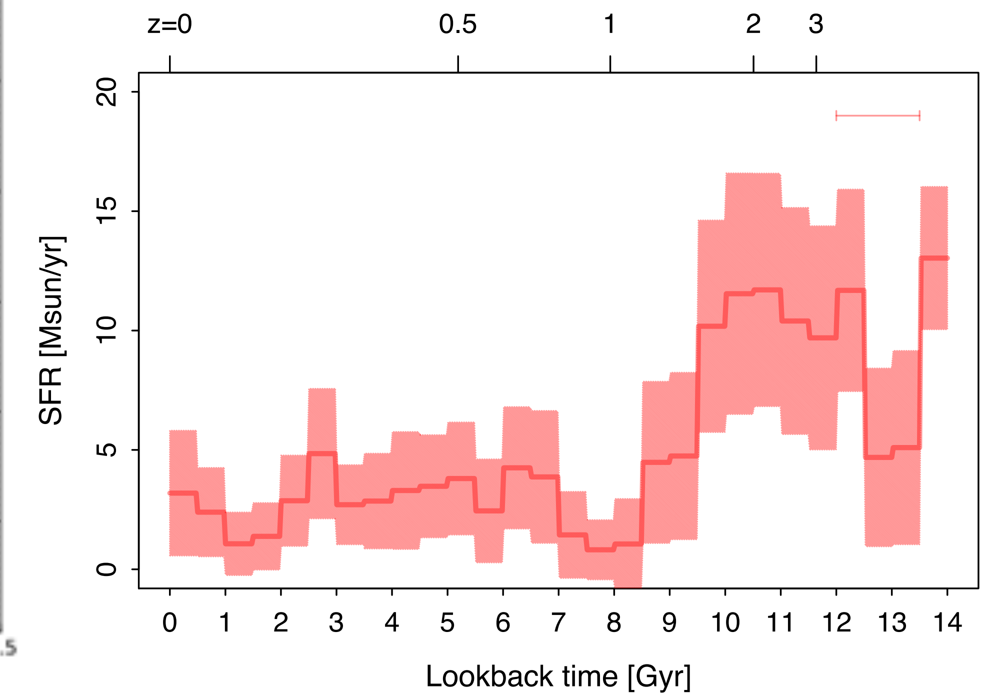
By estimating the fraction of "GC-like" stars, we can set a lower limit to the mass and number of destroyed GCs, and estimate their contribution to the field.

THE GALACTIC GLOBULAR CLUSTER SYSTEM

Jean-Baptiste et al,in prep



Haywood e al 2013



To build a global picture of the history of SF in the Galaxy, and of its evolution, we need - among other things - to compare the chemical properties of the GC system with those of field stars.

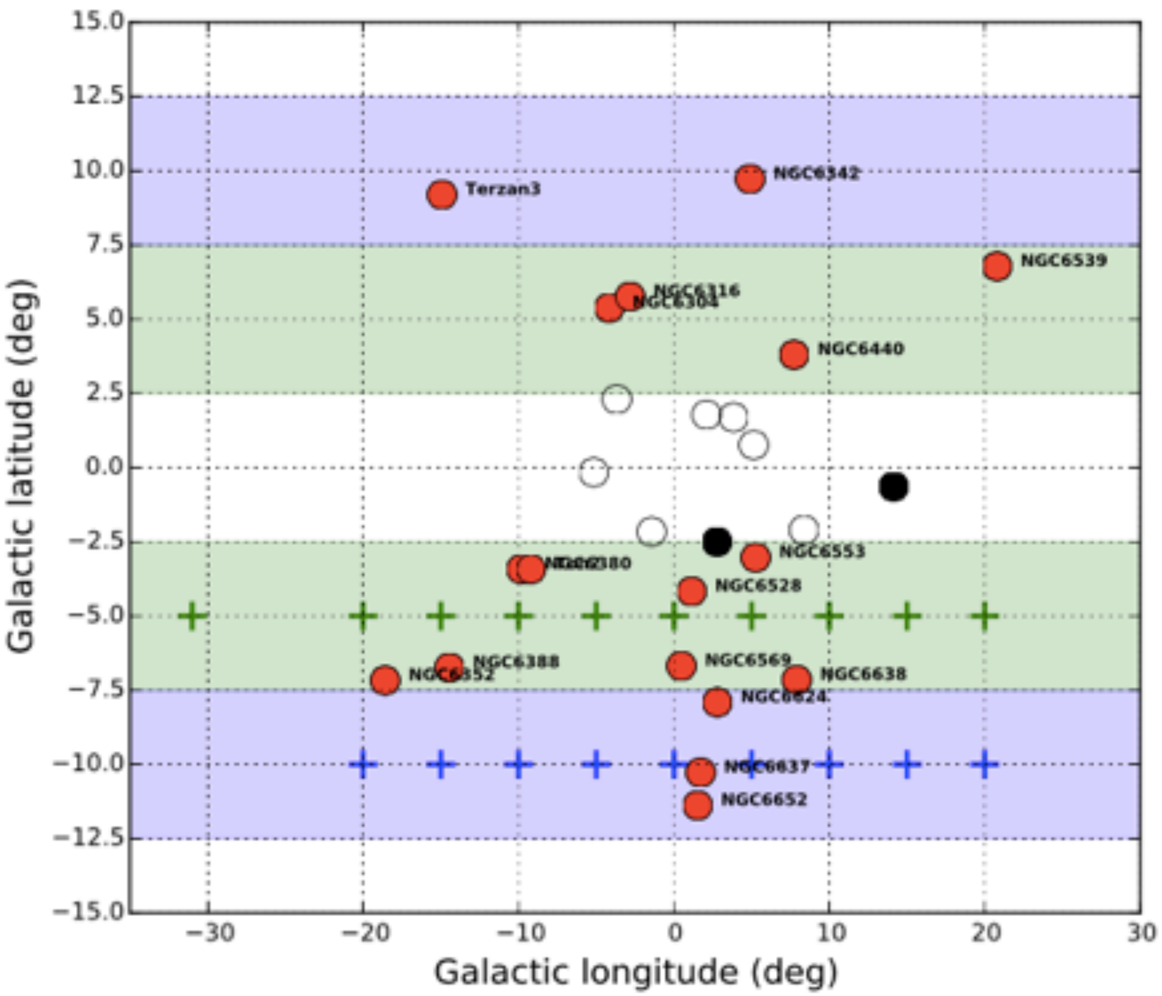
This is still very difficult and sometime frustrating :

often small statistics for each cluster,

different clusters observed with different instruments, by different groups, systematics, ..

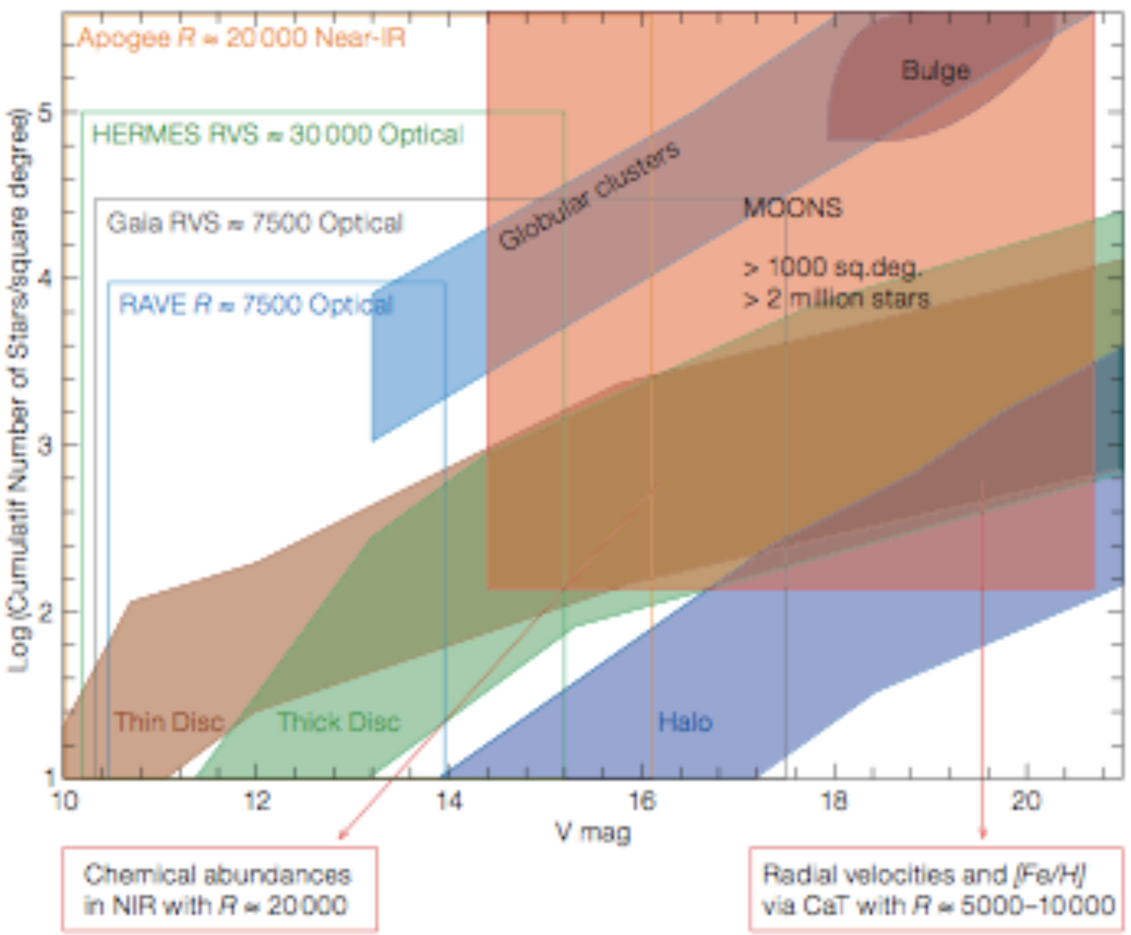
Difficult for any global comparison.

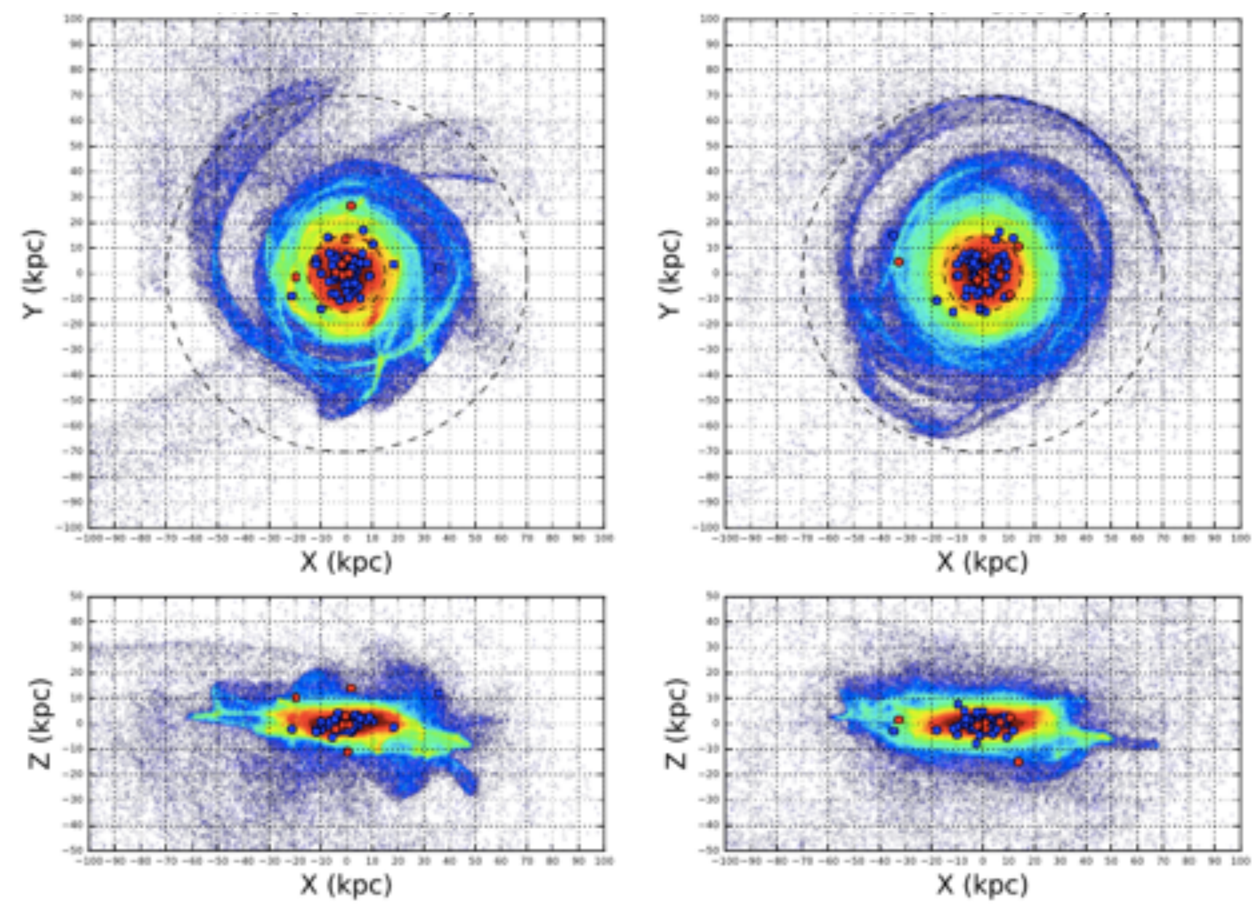
THE GALACTIC GLOBULAR CLUSTER SYSTEM



A survey of the inner MW GC system, characterized by a large statistics/cluster and by observing 10-20 clusters, would allow to have for the first time a global and consistent view of the GC system and the field populations

ACCRETED STARS IN THE GALAXY : LOOKING FOR THE MASSIVE BUILDING BLOCKS



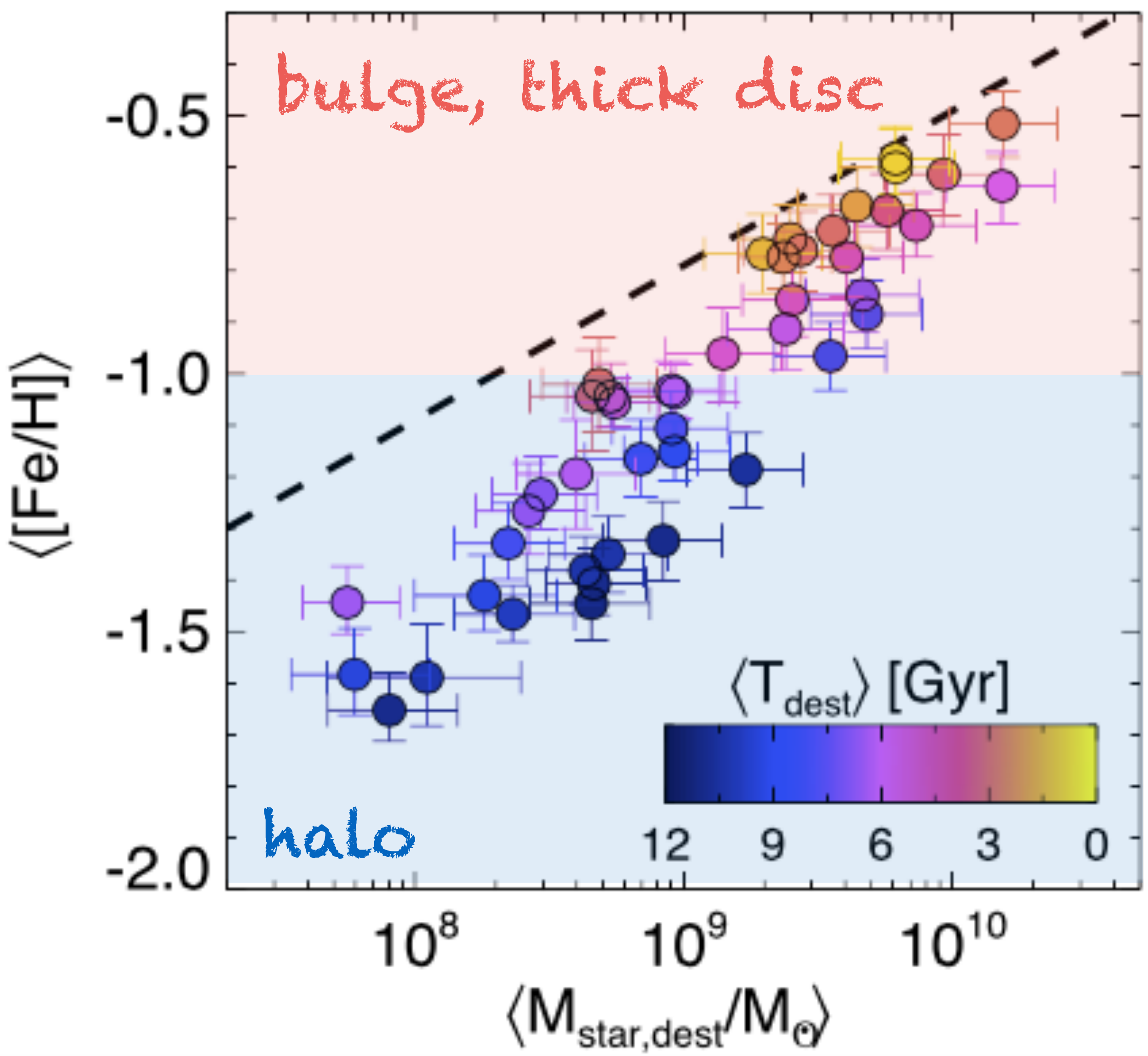


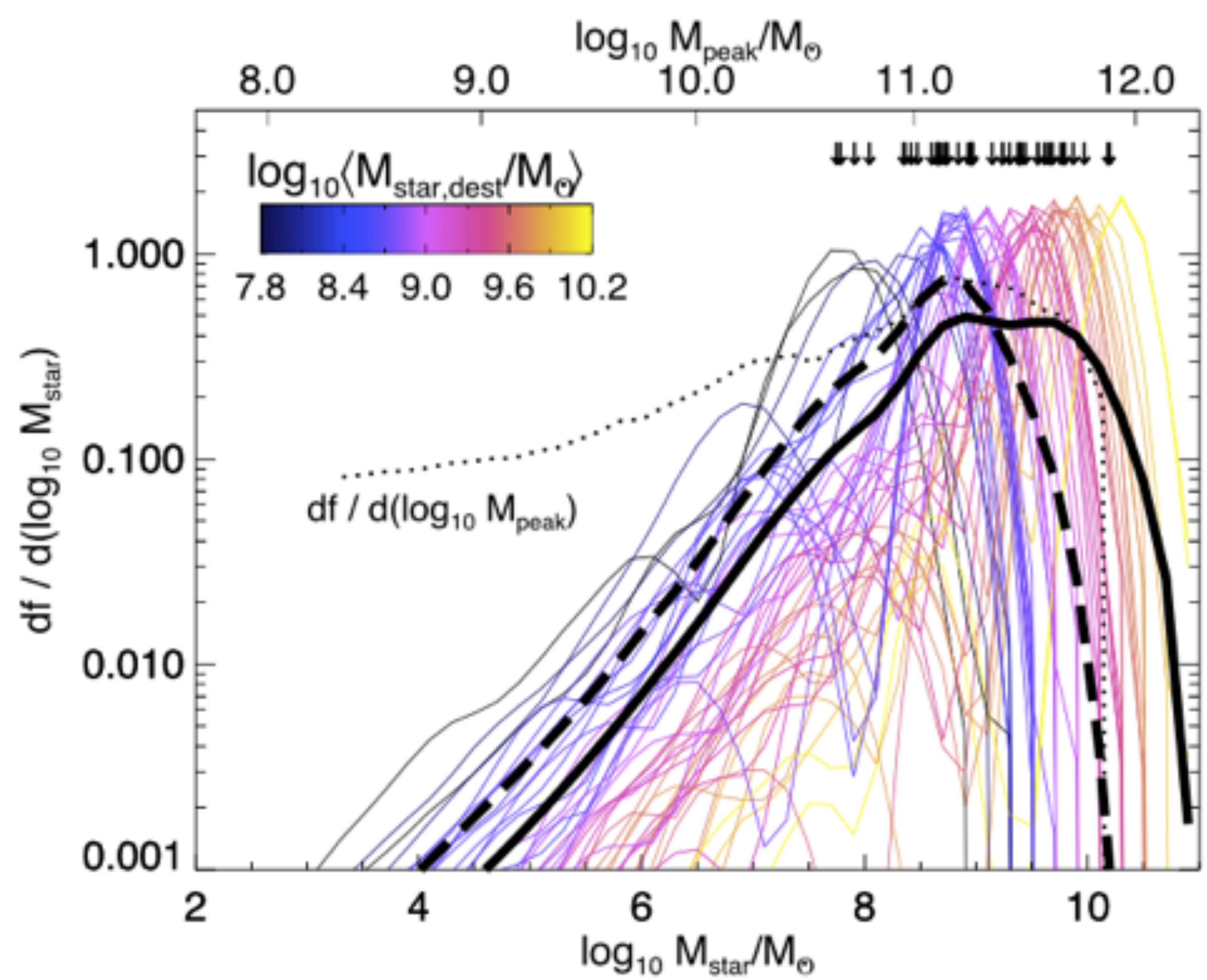
How (and where) to find the remnants of ancient accretion events ?

ACCRETED STARS IN THE GALAXY : LOOKING FOR THE MASSIVE BUILDING BLOCKS

Cosmological models suggest that the dominant contributors to the accreted stellar mass of MW-type halos are relatively massive dwarfs with Mstar ~ 10^8 – 10^{10}M⊙.

The simulations seem thus to favor 1:10 mass ratios as the main contributors, rather than lots of 1:100 events (see,for ex, Deason et al 2016)

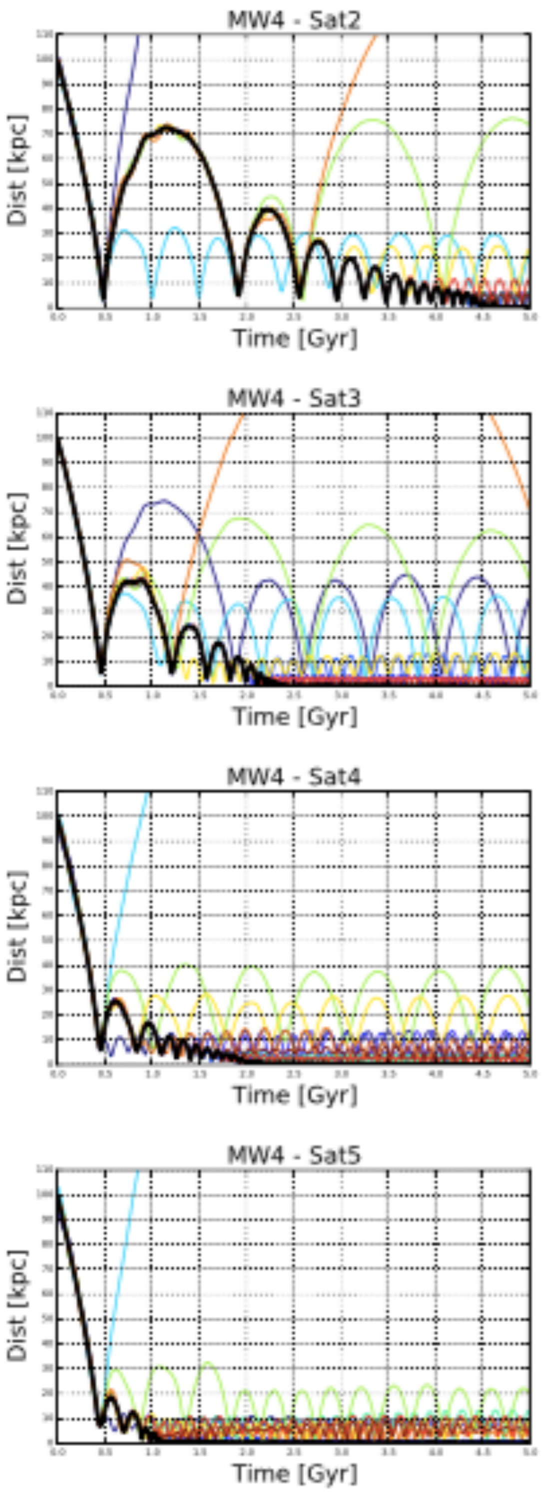


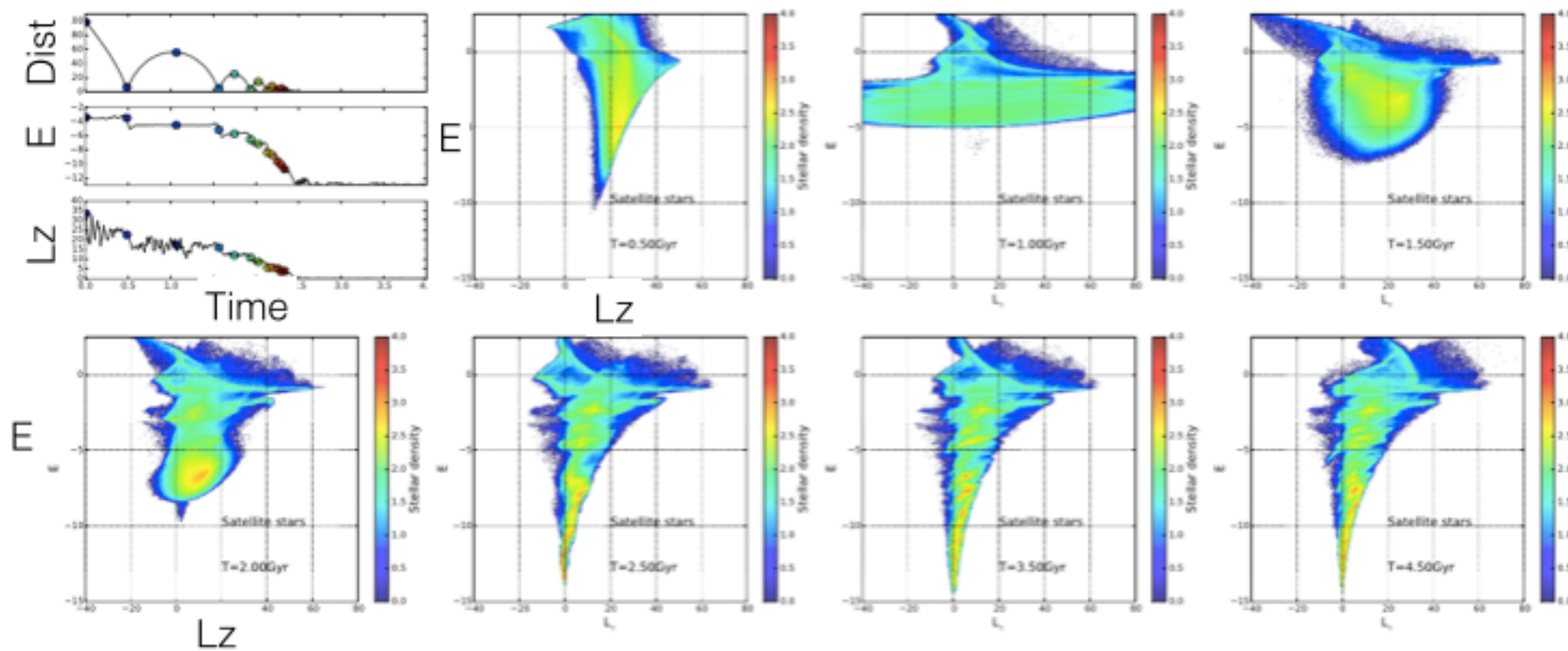


Deason et al 2016

ACCRETED STARS IN THE GALAXY : LOOKING FOR THE MASSIVE BUILDING BLOCKS

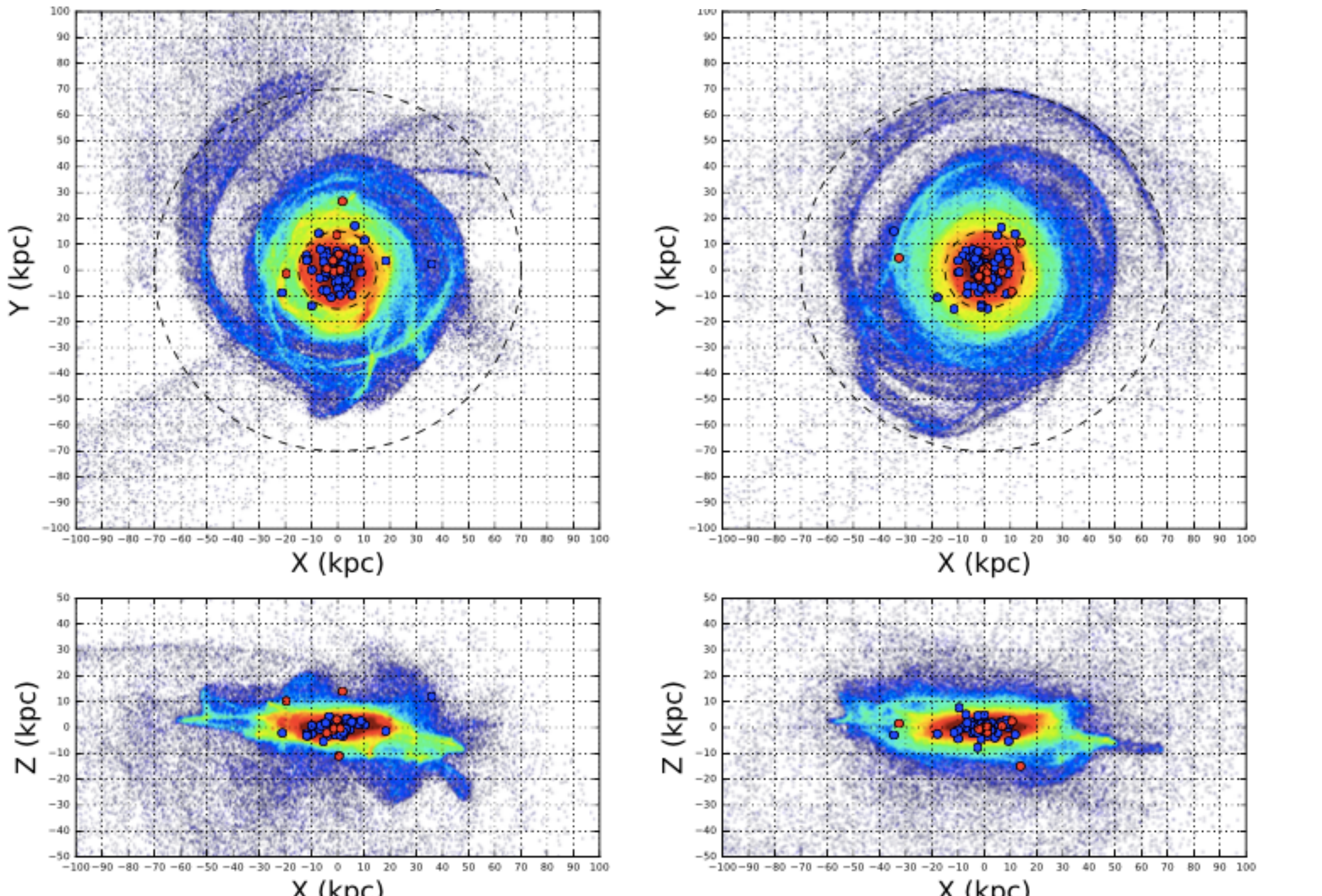
Also dynamical arguments suggest that relatively massive (~1:10) satellites can be efficiently brought into the inner kpcs of a MW-type galaxy on few Gyrs, by dynamical friction.





Jean-Baptiste et al,submitted

ACCRETED STARS IN THE GALAXY : LOOKING FOR THE MASSIVE BUILDING BLOCKS



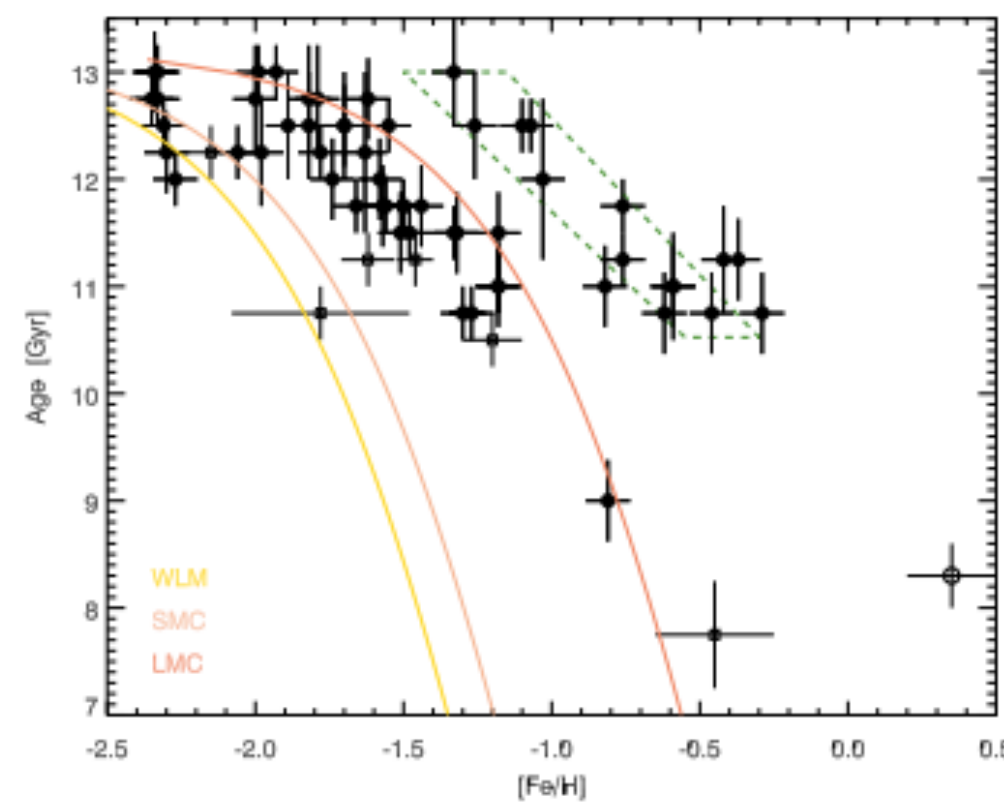
Jean-Baptiste, PhD thesis

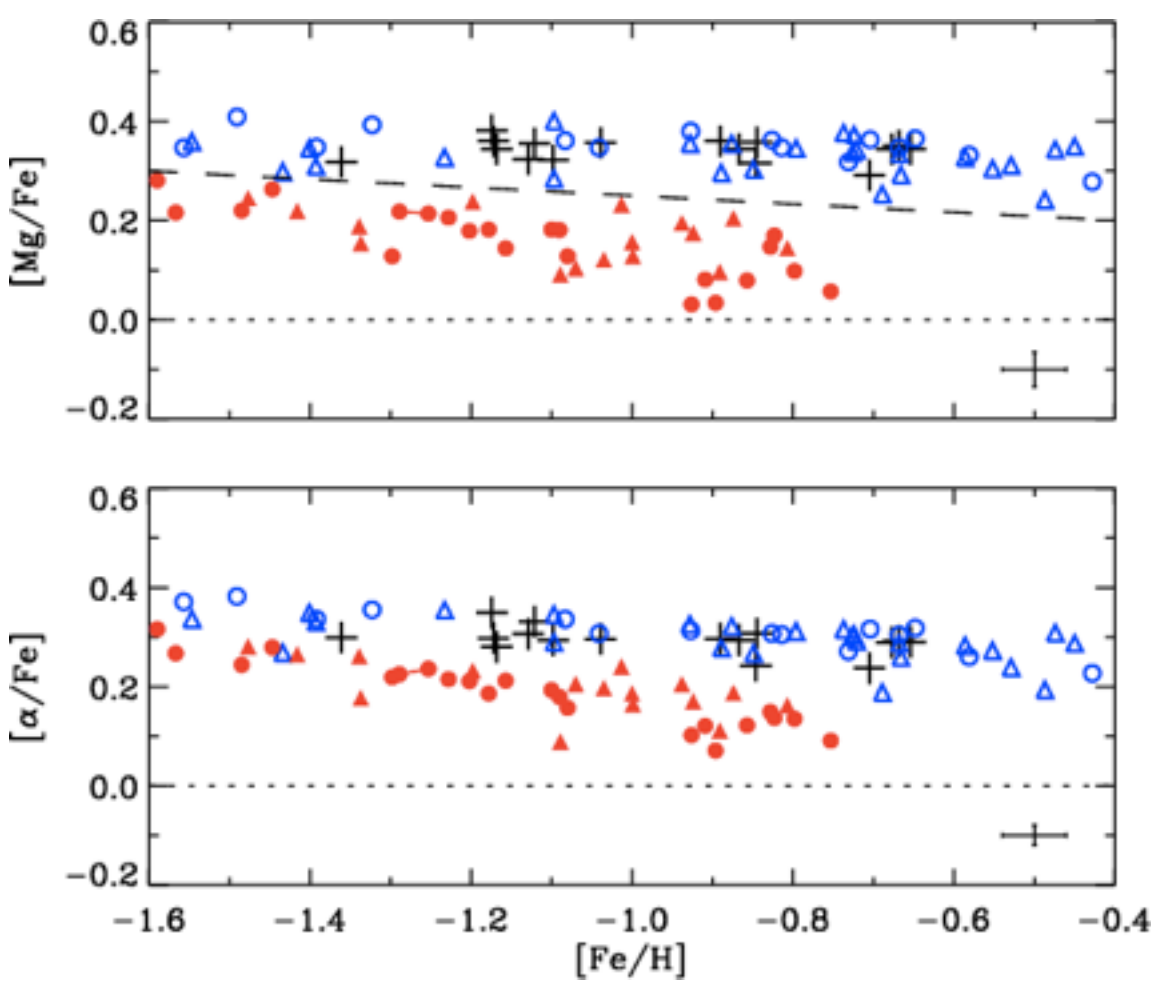
ACCRETED STARS IN THE GALAXY : LOOKING FOR THE MASSIVE BUILDING BLOCKS

A survey of the inner disc/bulge regions with MOONS can help finding these massive building blocks.

How ? By **looking for chemical patterns** distinct from those of the majority of field stars and globular clusters

Leaman et al 2013

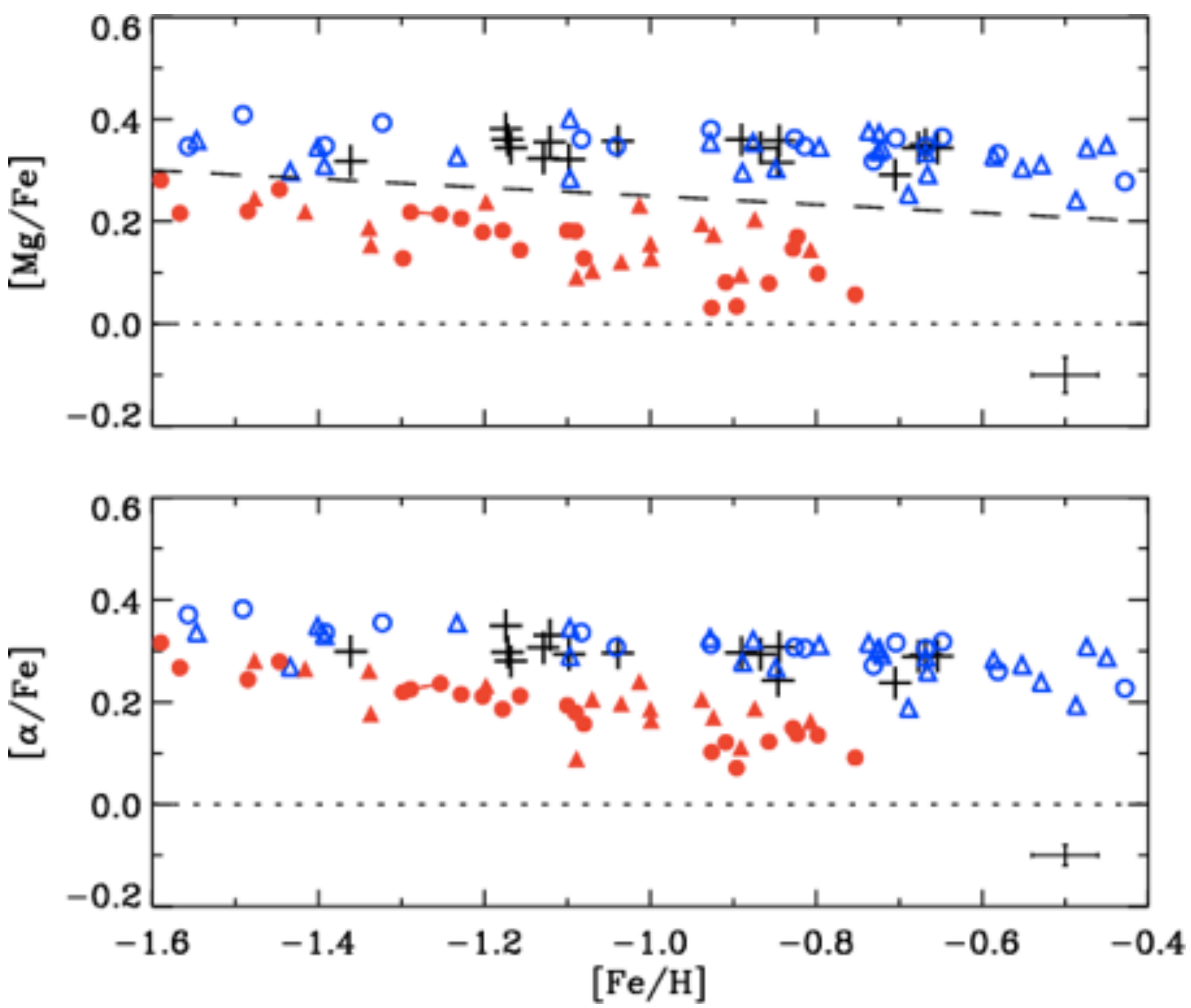




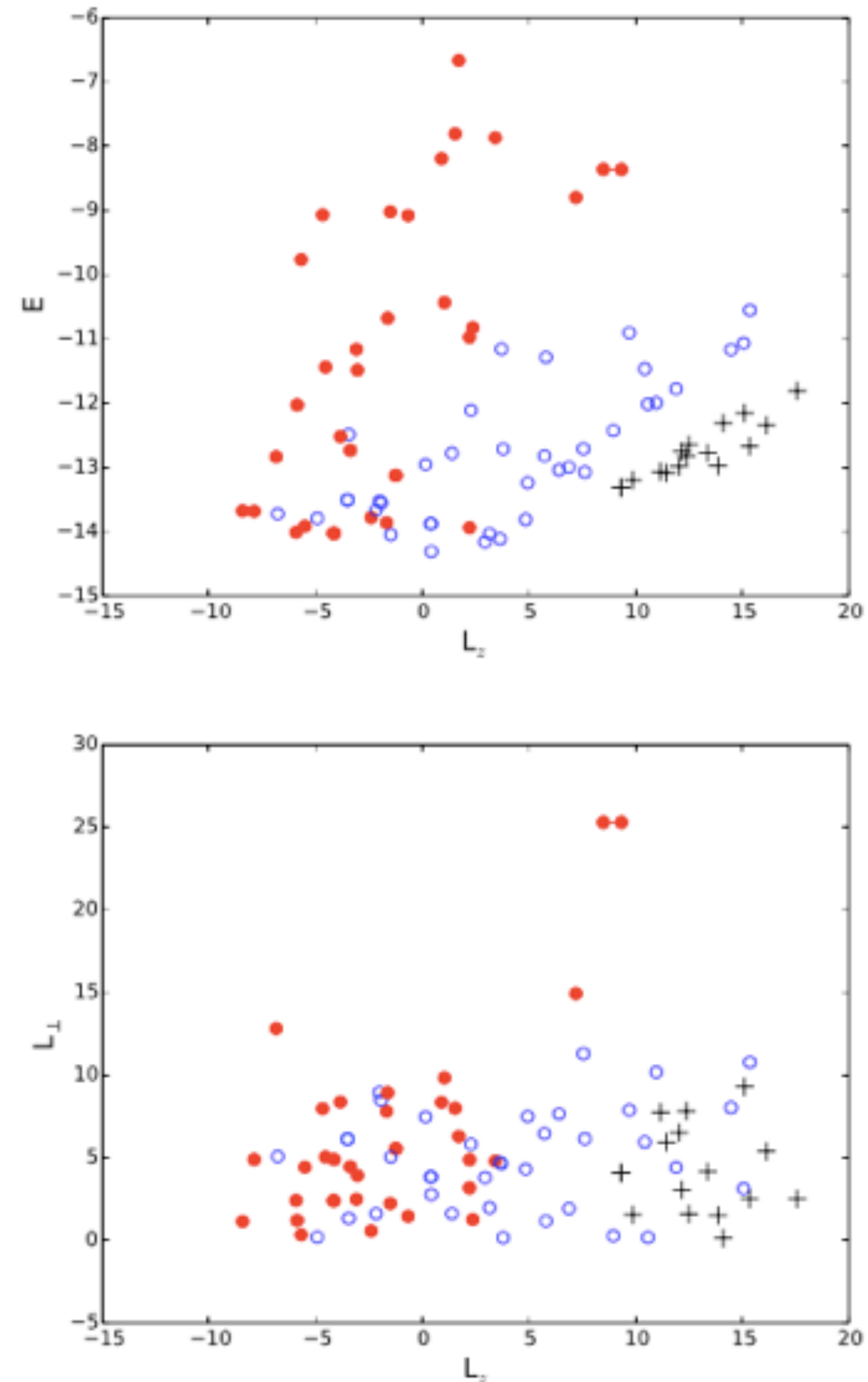
left : Nissen & Schuster 2010, but see also the ongoing work by Recio-Blanco et al on low-alpha stars in the bulge with GES

ACCRETED STARS IN THE GALAXY : LOOKING FOR THE MASSIVE BUILDING BLOCKS

Note : kinematic diagnostics (E-Lz, L-Lz spaces, .. see the review by Smith et al 2015) inefficient to distinguish accreted from in-situ populations



Nissen & Schuster 2010,



Jean-Baptiste et al, submitted