N-BODY MODELS OF THE MILKY WAY BULGE
&
THE ORIGIN OF ITS METAL-POOR COMPONENT(s)

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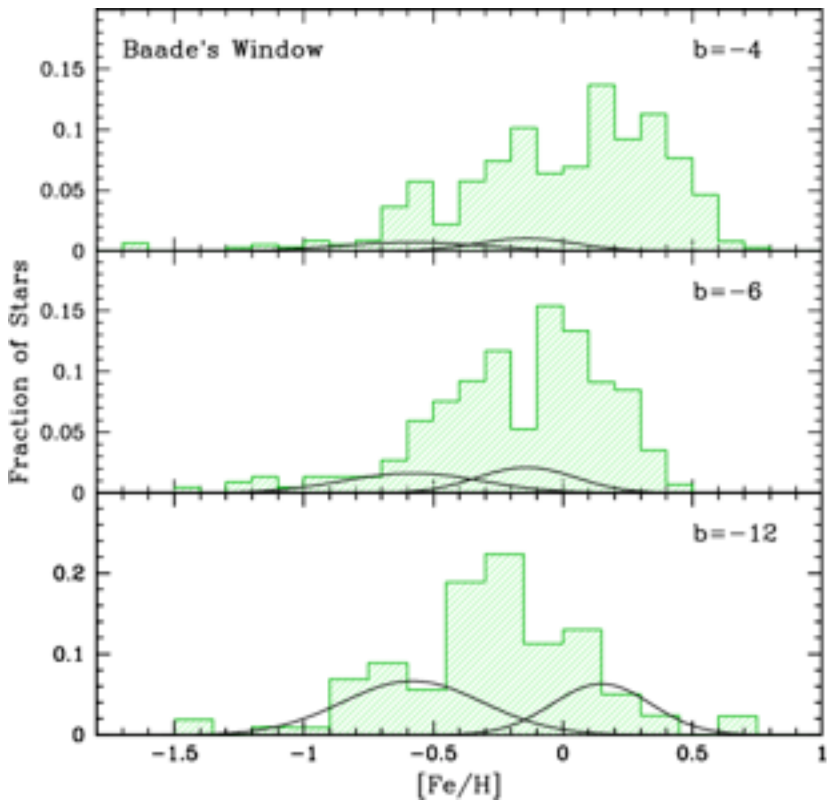
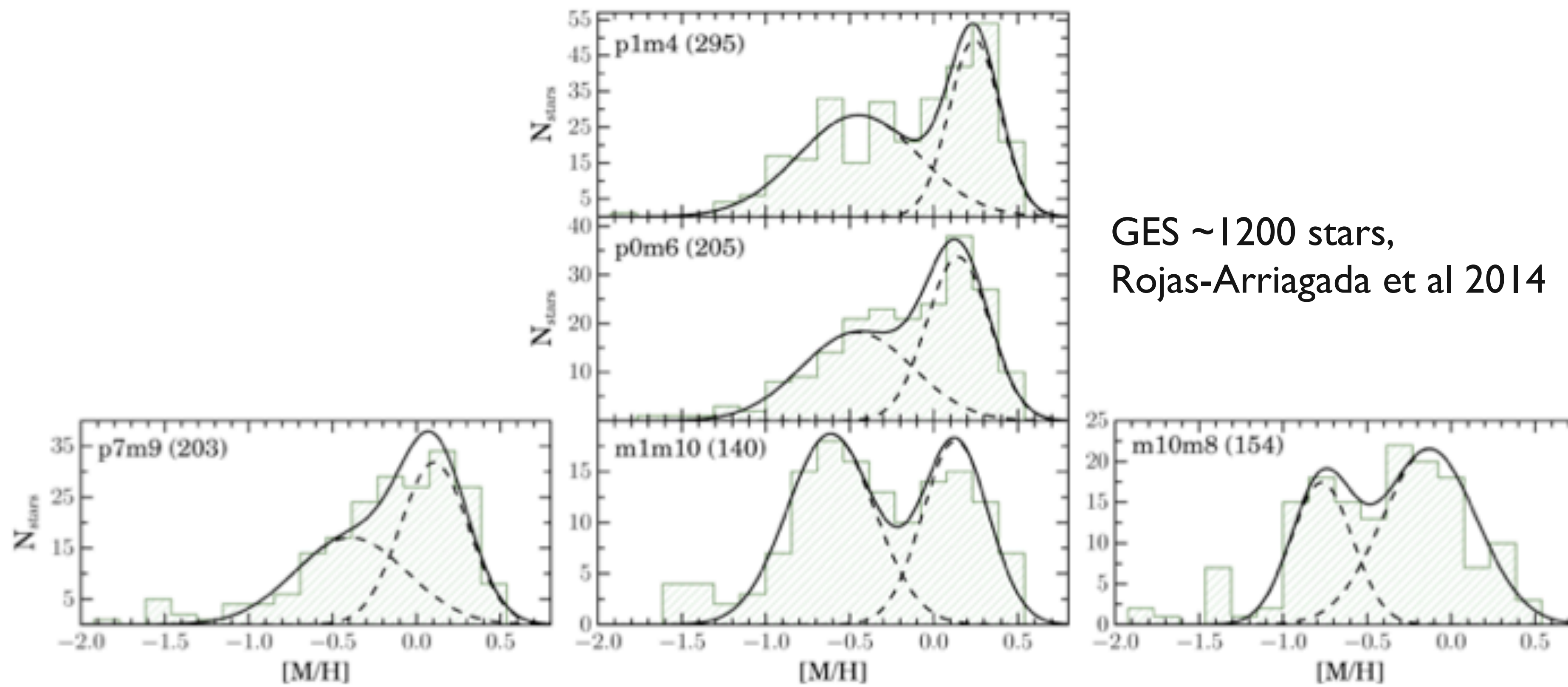
MULTIPLE POPULATIONS IN THE MW BULGE

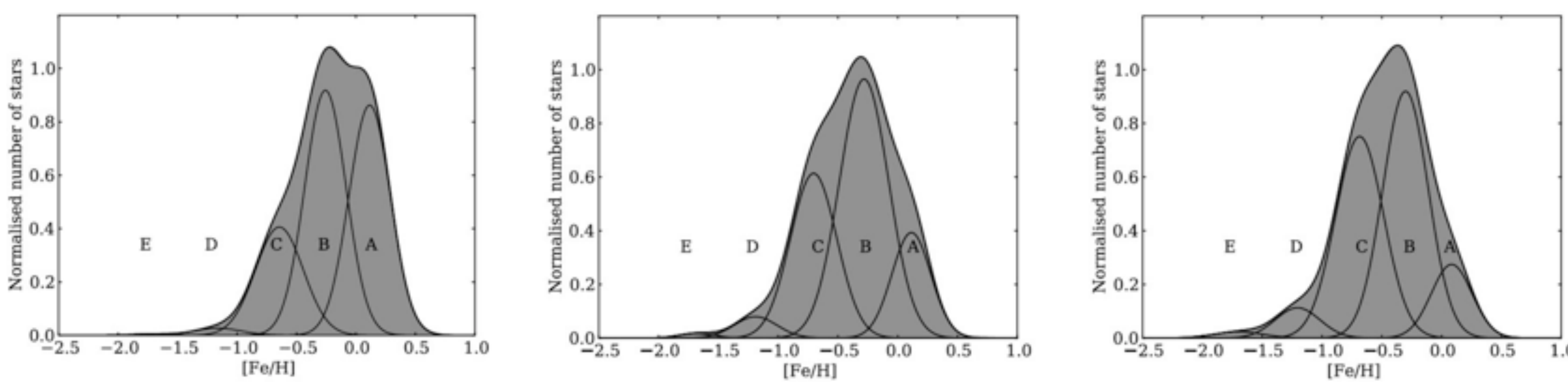
GIRAFFE, 800 stars, Zoccali et al 2008



GES ~1200 stars, Rojas-Arriagada et al 2014



ARGOS ~14000 stars, Ness et al 2013



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

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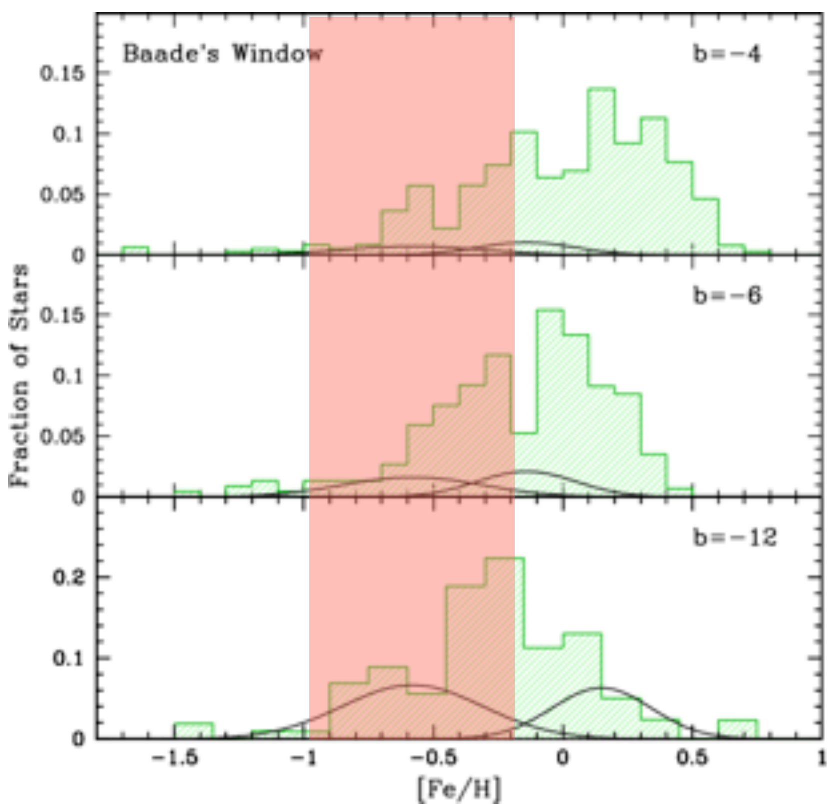

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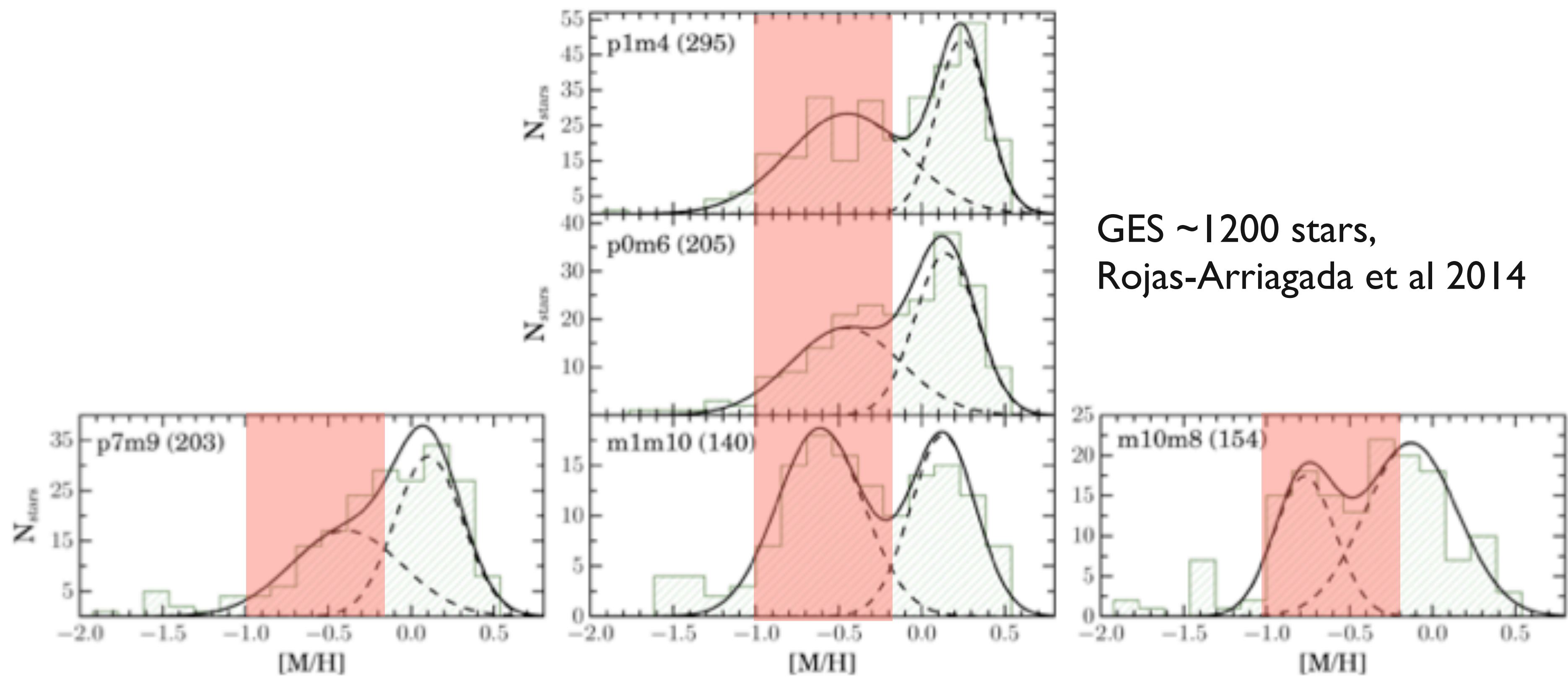

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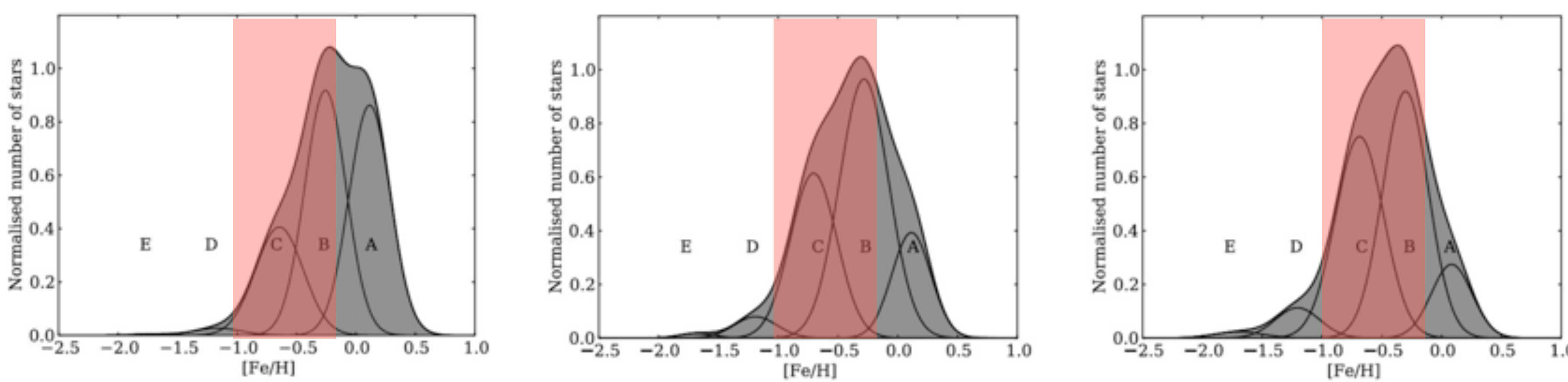


(a) $l \pm 15°, b = -5°$ (b) $l \pm 15°, b = -7.5°$ (c) $l \pm 15°, b = -10°$

MULTIPLE POPULATIONS IN THE MW BULGE

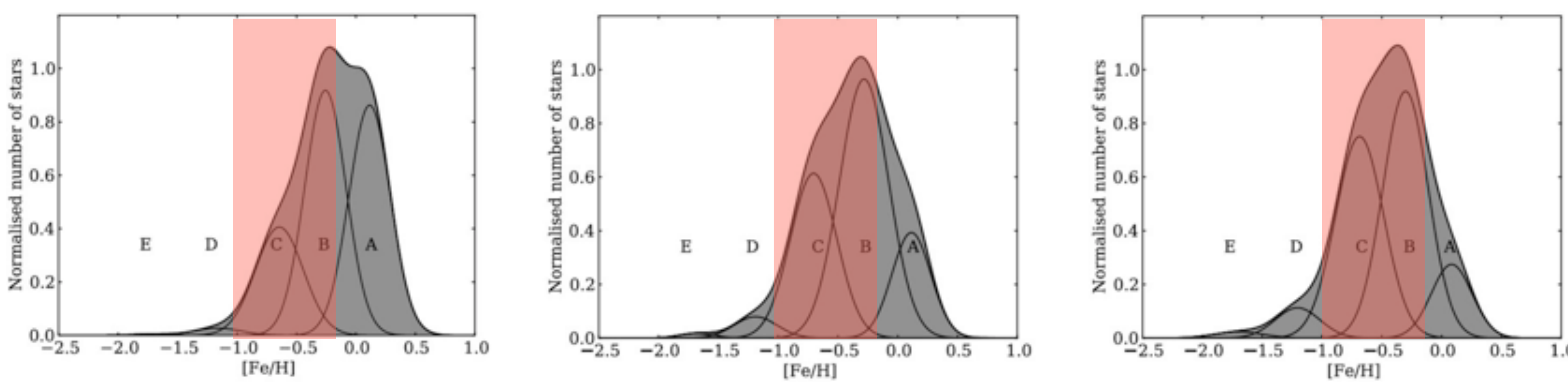
Scenarios :

1/ The MW bulge is a boxy/peanut-shaped bar originated in the thin disk

2/ The MW bulge is a boxy/peanut-shaped bar originated in the thin disk + a classical bulge

3/ The MW bulge is a boxy/peanut shaped bar originated in a thin+thick disk

ARGOS ~14000 stars, Ness et al 2013



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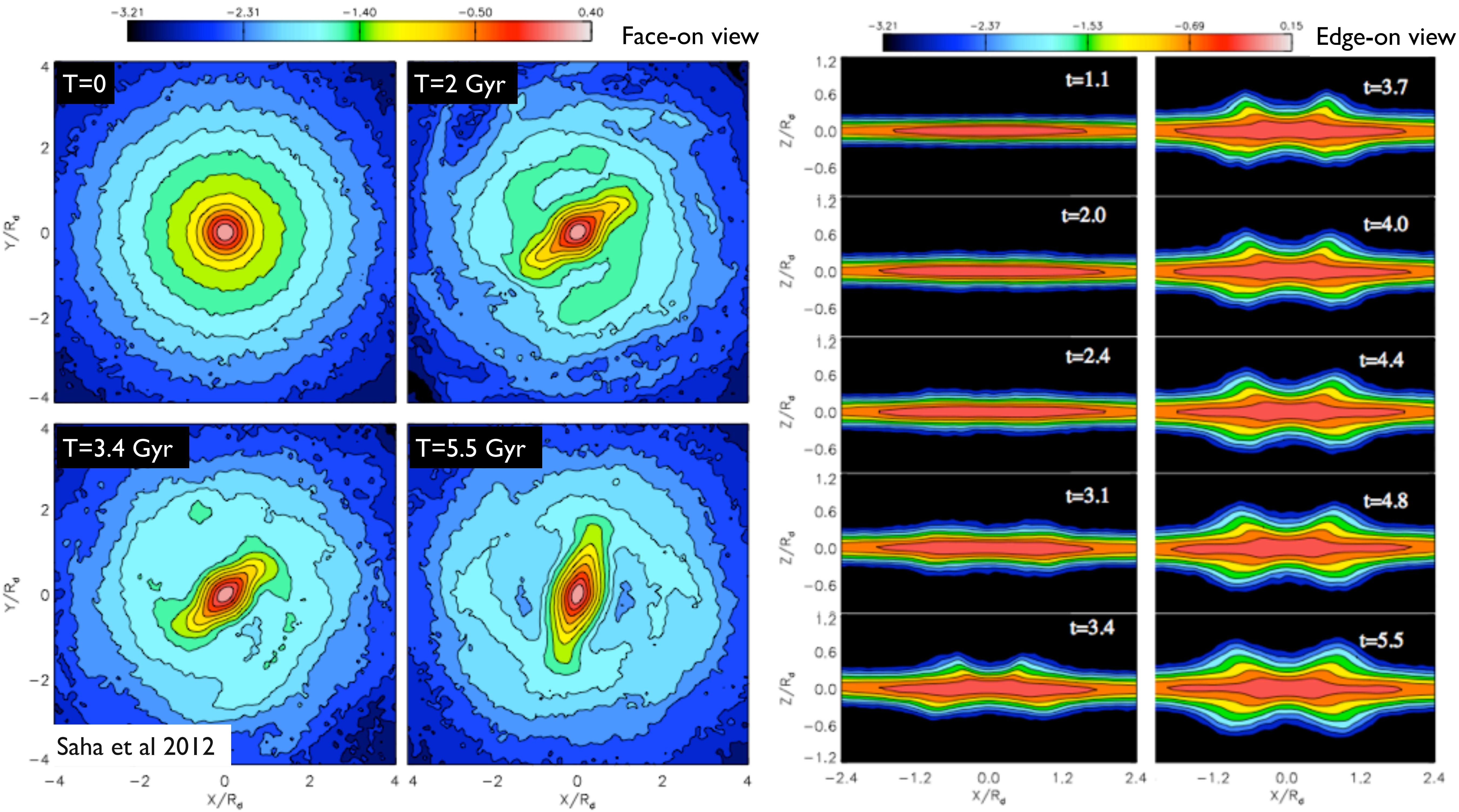
BOXY/PEANUT SHAPED BULGES

The MW is barred and its bulge has a boxy/peanut-shaped structure (Dwek et al 1995).

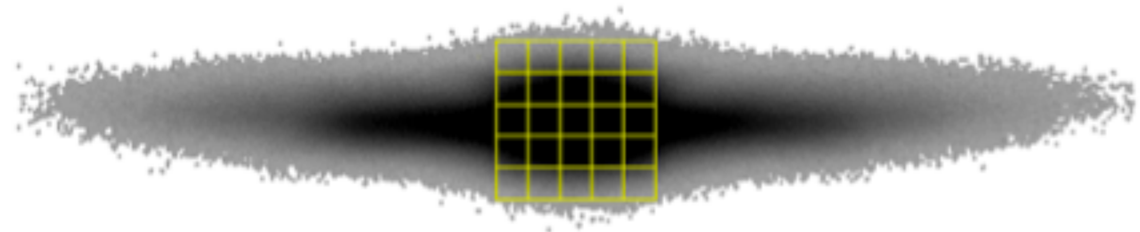
Boxy-peanut shaped structures are not rare, since they are present in about half of edge-on disc galaxies (see Lutticke et al. 2000)

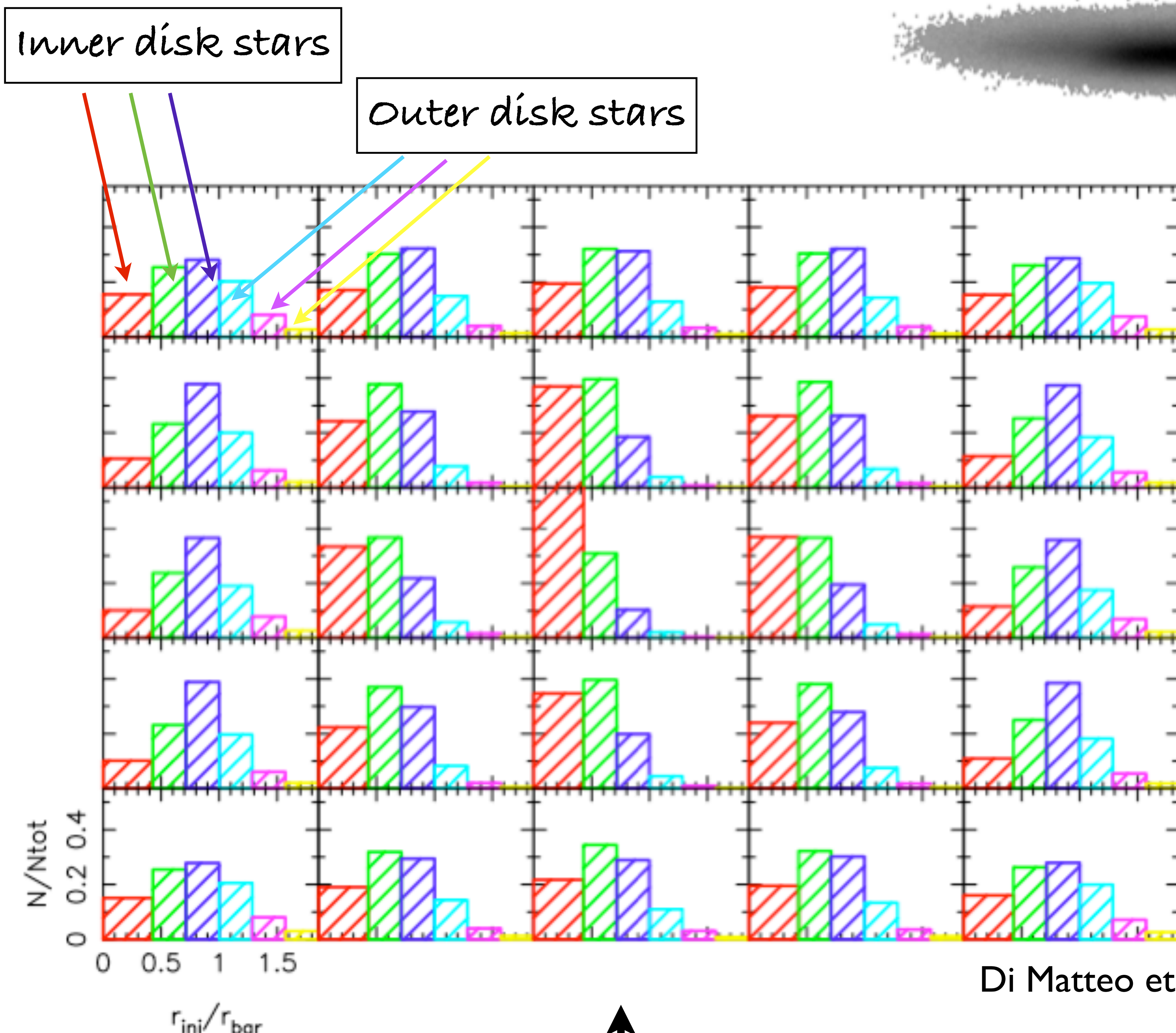


THE ORIGIN OF THE BULGE METAL-POOR POPULATION IN A PURE THIN DISK SCENARIO

SCENARIO 1:
THE MAPPING OF A THIN DISK INTO A BOXY BULGE

Where do stars ending-up in a boxy bulge come from ? (see Di Matteo et al 2014a)





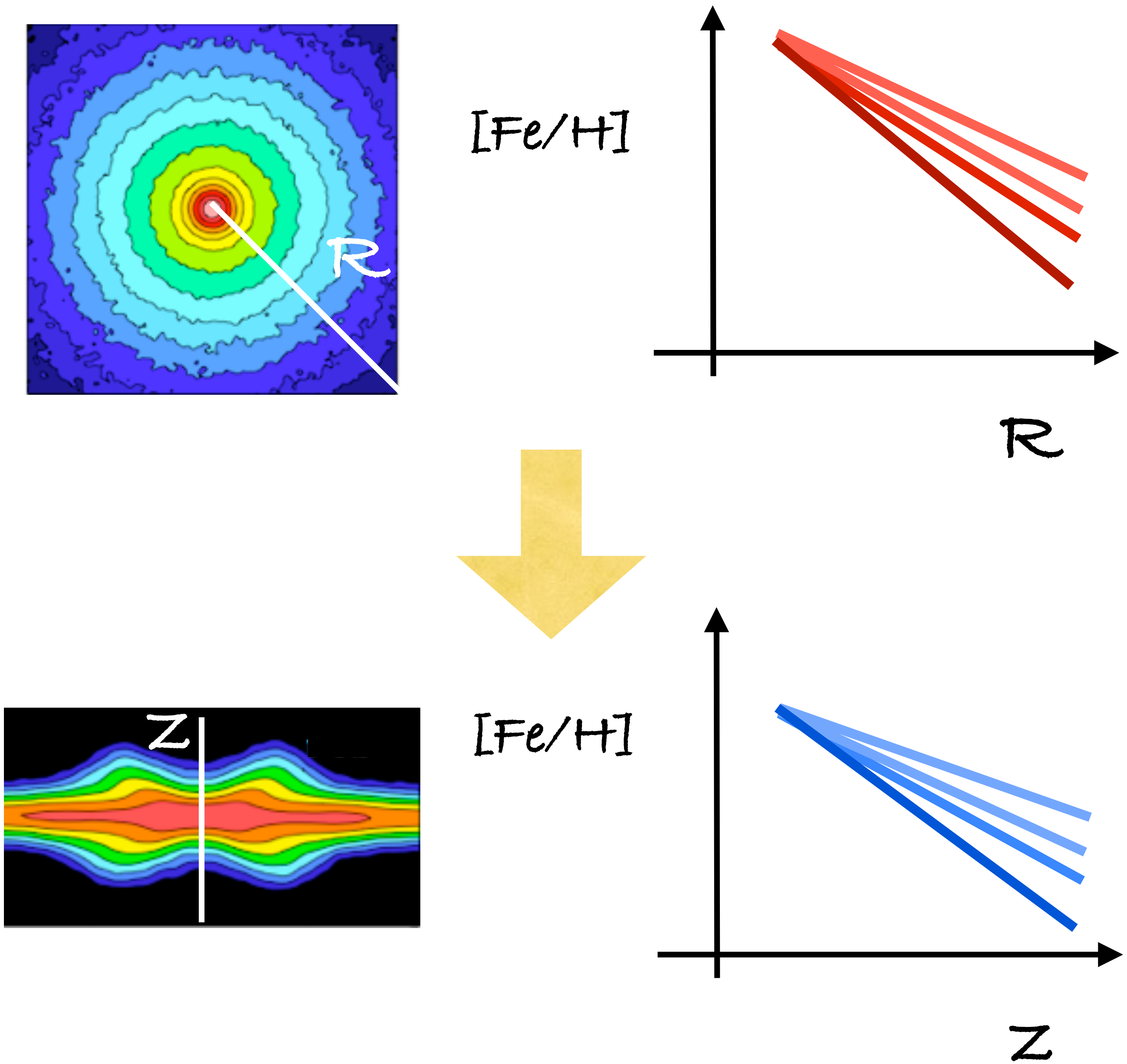
Di Matteo et al 2014a

bar minor axis

- A boxy bulge is made of stars born in the inner disk as well as stars originated in the outer disk, up to the OLR
- Outer thin disk stars preferentially found at high latitudes and longitudes
- Inner and outer disk stars part of the peanut structure

SCENARIO 1: THE MW BULGE ALL ORIGINATED IN A THIN DISC

How can we explain the presence of a metal-poor component in this scenario ?
(see Martínez-Valpuesta & Gerhard 2013)



An initial
(= *before bar formation*)
negative radial metallicity gradient in the stellar disk reflects into a vertical negative metallicity gradient in the boxy bulge

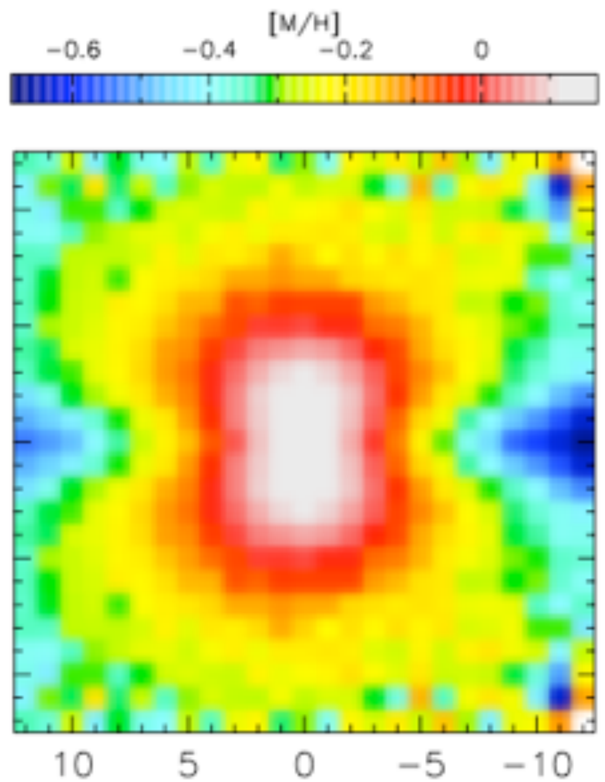
SCENARIO 1: THE MW BULGE ALL ORIGINATED IN A THIN DISK

Success : global bulge metallicity

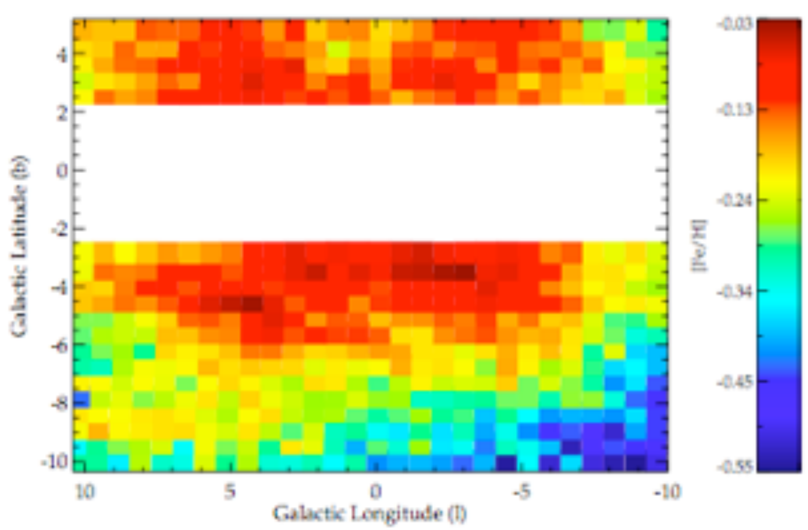
If the initial negative radial metallicity gradient in the stellar disk is steep enough (~-0.4 dex/kpc) a vertical negative metallicity gradient similar to those measured in the bulge can be produced

(see Martinez-Valpuesta & Gerhard 2013; confirmed by Di Matteo et al 2014b)

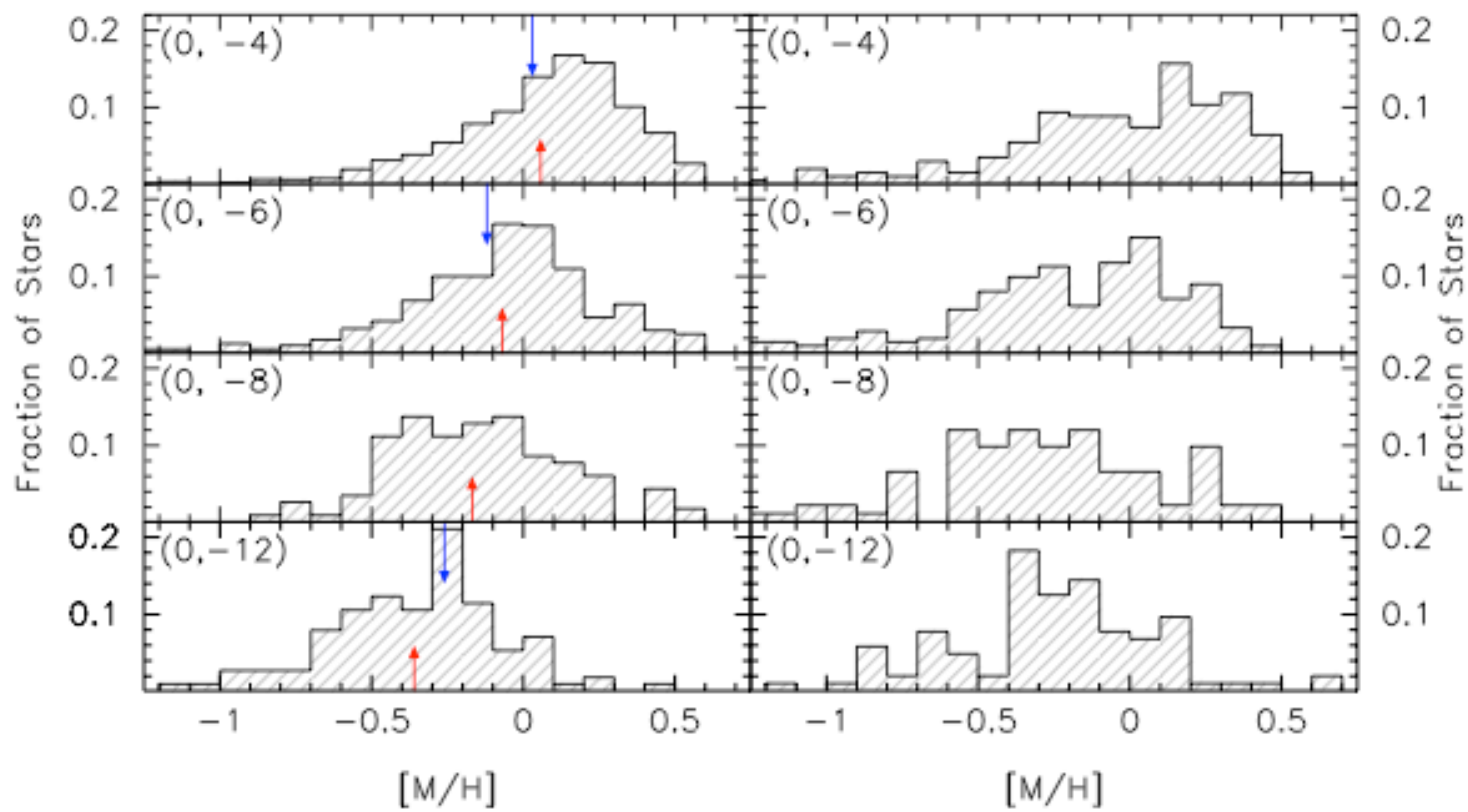
Simulation by MV&G13



VVV Survey, Gonzalez et al 2013

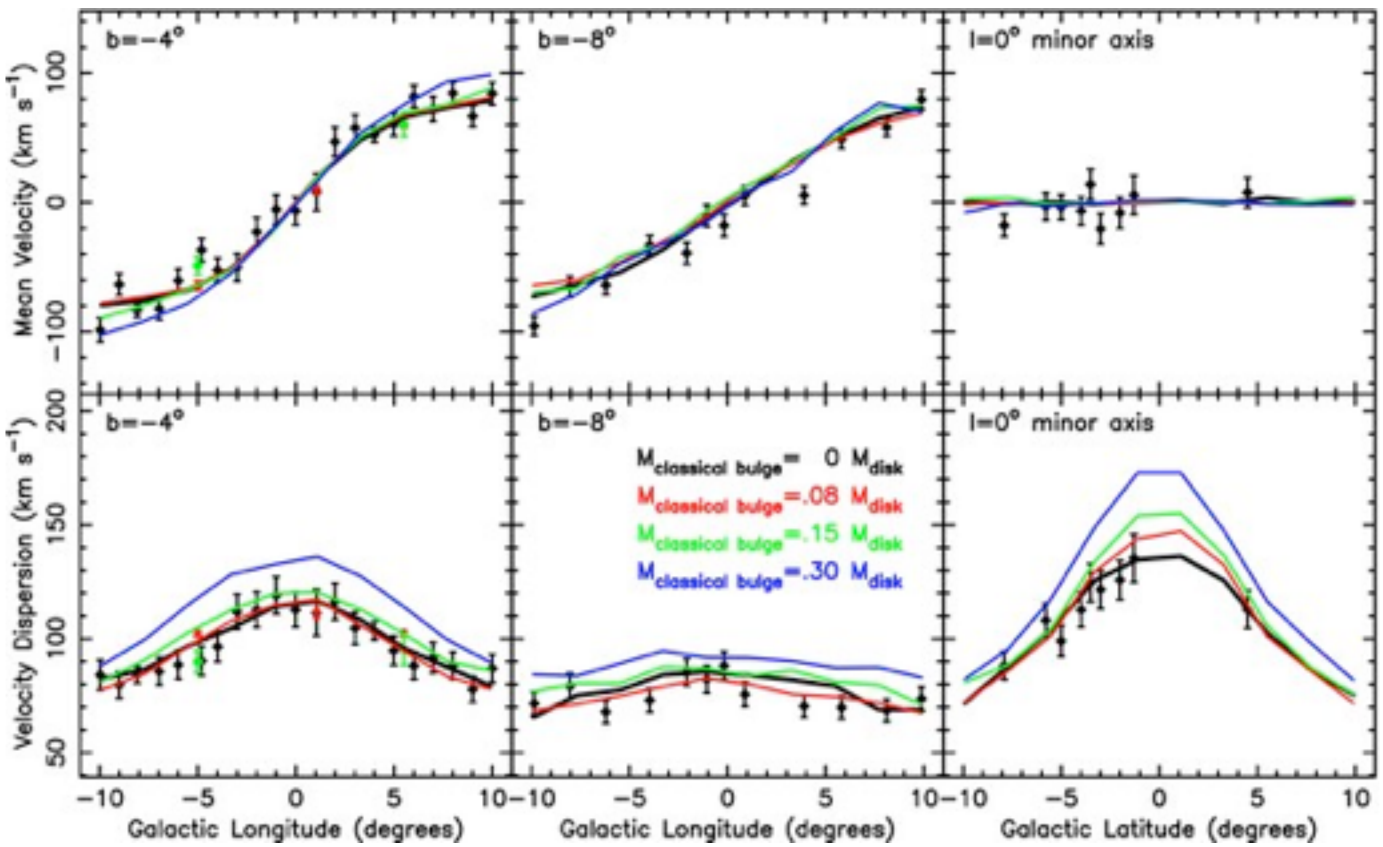


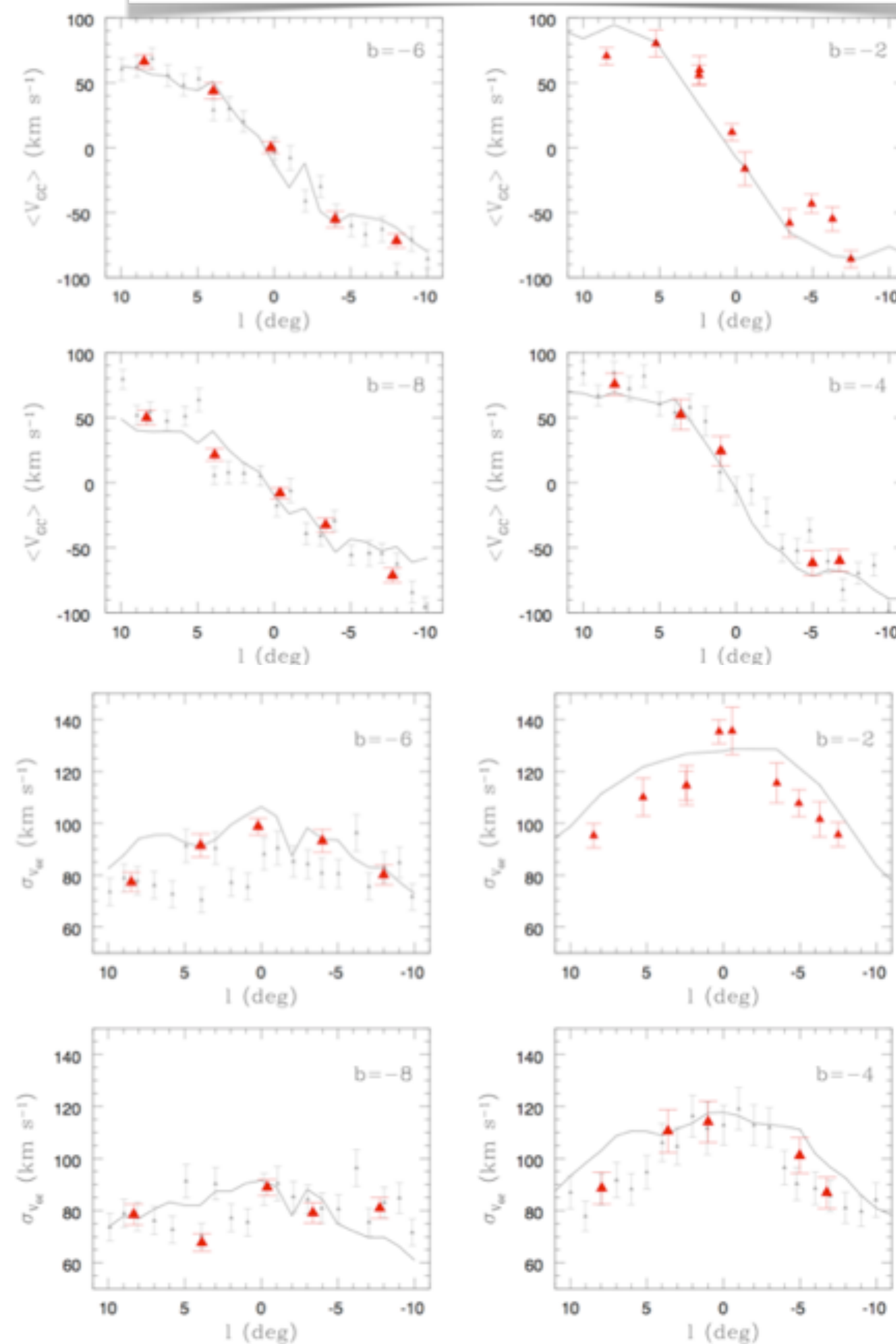
Simulations from MV & G 2013 data from Zoccali et al 08



SCENARIO 1: THE MW BULGE ALL ORIGINATED IN A THIN DISC

Success : global bulge kinematics





Shen et al 2010: "The MW as a pure thin disk galaxy, any classical bulge contribution cannot be larger than ~8% of the disk mass."

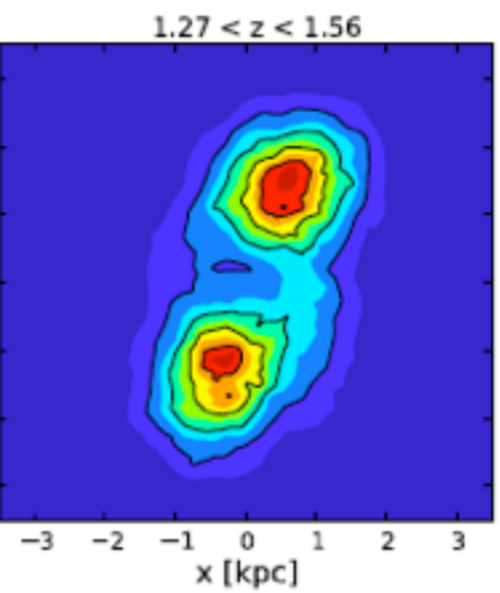
Zoccali et al 2014: "The very good agreement between this model and the data supports the conclusion presented in Shen et al. (2010), extending it to the inner bulge at b = –2"

SCENARIO 1: THE MW BULGE ALL ORIGINATED IN A THIN DISC

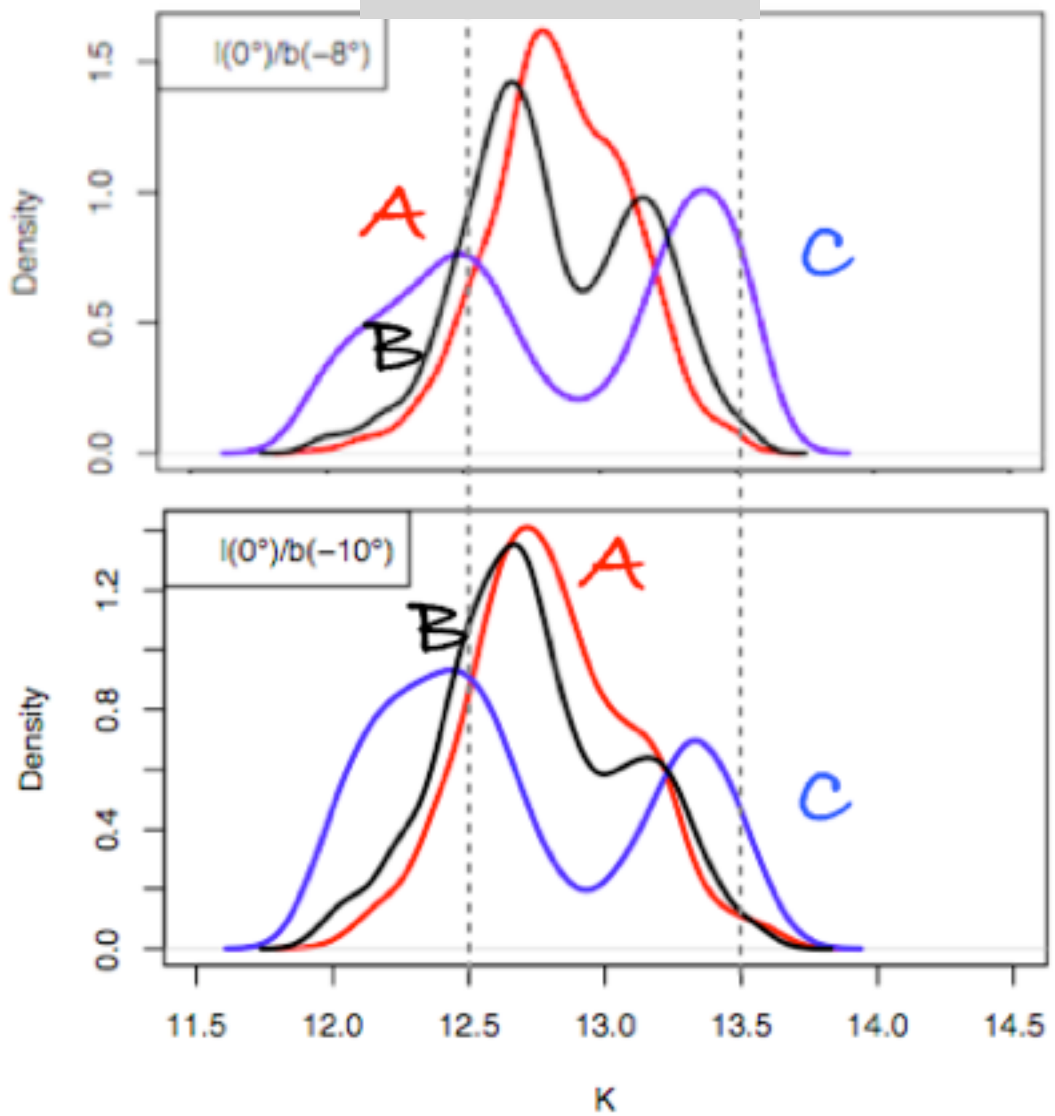
Failure : K-magnitude distribution of metal-poor stars

In this scenario, **outer disk, metal-poor stars in the bulge also part of the peanut structure.** This implies that **they should show a split in the K-magnitude distribution, characteristic of stars in the peanut.**

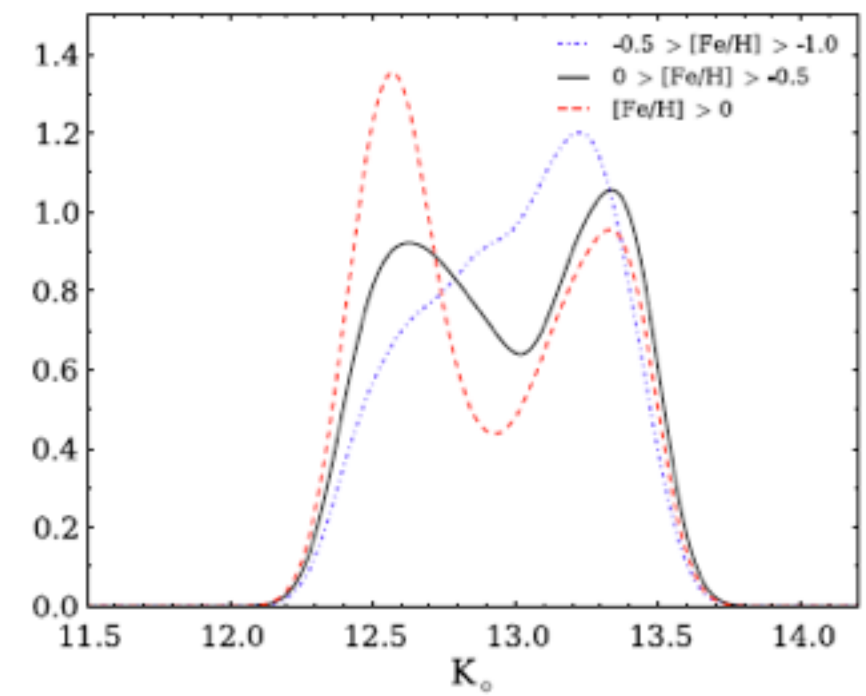
This seems not observed



Simulations



ARGOS data



A : [Fe/H] >0
B : -0.5 < [Fe/H] <0
C : -1 < [Fe/H] < -0.5

Ness et al 2012

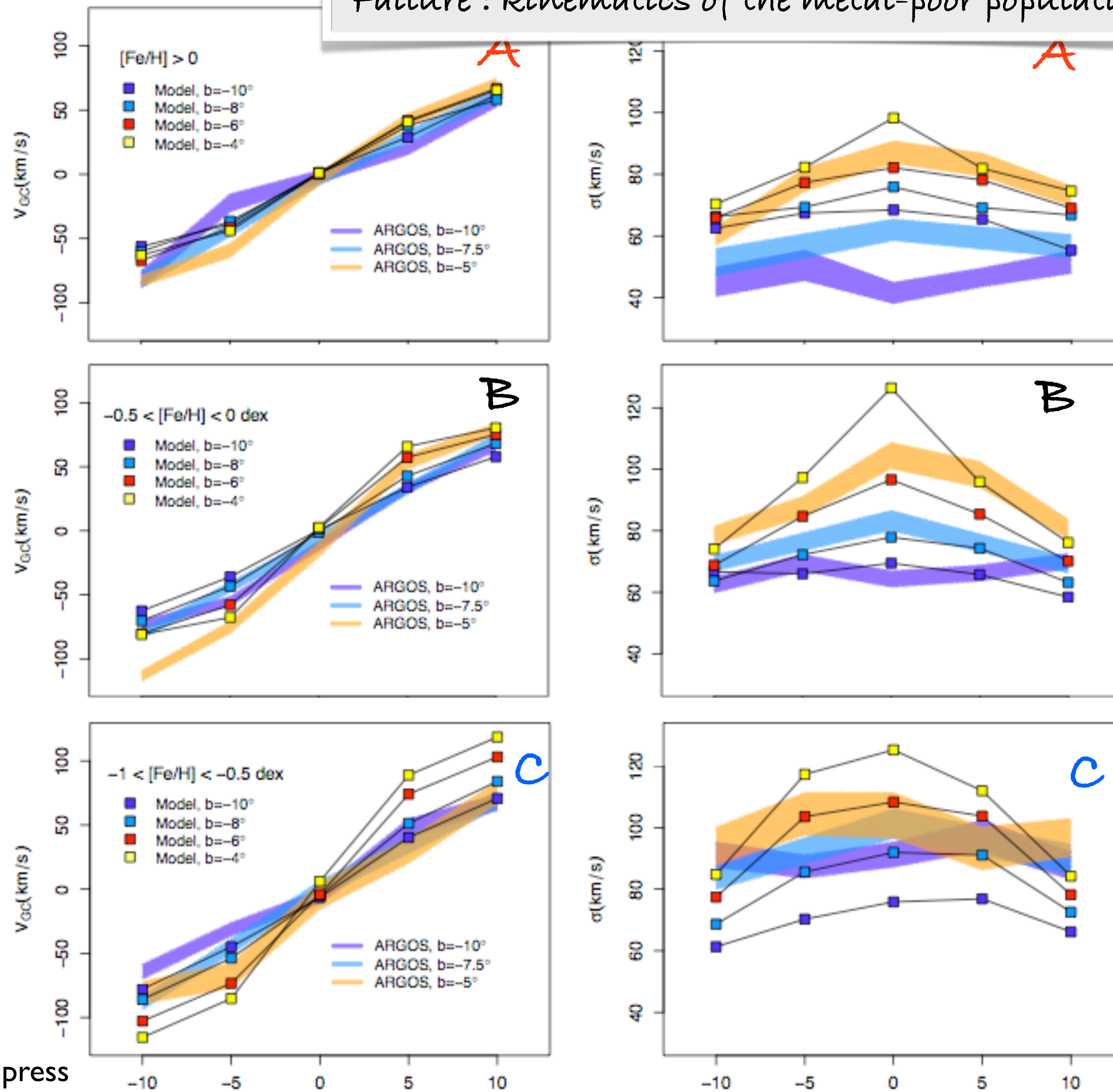
Di Matteo et al 2014b, A&A in press

SCENARIO 1: THE MW BULGE ALL ORIGINATED IN A THIN DISC

Failure : kinematics of the metal-poor population

Moreover, **in such scenario, population C should have a more external origin than A & B.**

This is not in agreement with the kinematics of population C



Di Matteo et al 2014b, A&A in press

CAN THE METAL-POOR COMPONENT BE A CLASSICAL BULGE ?

Kormendy & Ho 2013 :

"**Classical bulges** are defined purely by observational criteria:
They are **indistinguishable from elliptical galaxies**,
except that they are embedded in disks (Renzini 1999)."

CAN THE METAL-POOR COMPONENT BE A CLASSICAL BULGE ?

NO, see Di Matteo et al 2014a

1. At latitudes ≥ -5°,
the metal-poor component dominates the mass,
see Ness et al 2013

$b°$	A	B	C
-5	0.39	0.37	0.22
-7.5	0.22	0.43	0.30
-10	0.11	0.50	0.31

In a thin disk bar+ classical bulge scenario,
our models do not reproduce such high fractions of metal-poor stars not even with B/D=25%.
And for a MW-type galaxy, a B/D=25% is definitely an upper limit (see Laurikainen et al 2007)

2. The metal-poor components rotate as fast at the most metal-rich one, this is difficult to explain in such a scenario.

Even if bulge stars can acquire some rotation during the bar formation/evolution process (see Saha et al 2012a,b), no N-body model has been able to reproduce a classical bulge rotating as fast as the thin disk so far.

CAN THE METAL-POOR COMPONENT BE A CLASSICAL BULGE ?

NO, see Di Matteo et al 2014a

Our conclusion is that the classical bulge in the MW is small (B/D~10%) or non-existent (see also, among others, Shen et al 2010, Kunder et al 2012).

This result is consistent with a number of studies of bulges in external galaxies (Kormendy et al 2010, Fisher & Drory 2011, Laurikainen et al 2014).

Kormendy et al 2010 : **"Bulgeless Giant Galaxies Challenge Our Picture of Galaxy Formation by Hierarchical Clustering"**

THE THICK DISK &
THE BULGE METAL-POOR POPULATION

THICK DISK AS A MAJOR MW COMPONENT

1. The thick disk as a short scale length
   (Bensby et al 2011; Bovy et al 2012; Anders et al 2014)

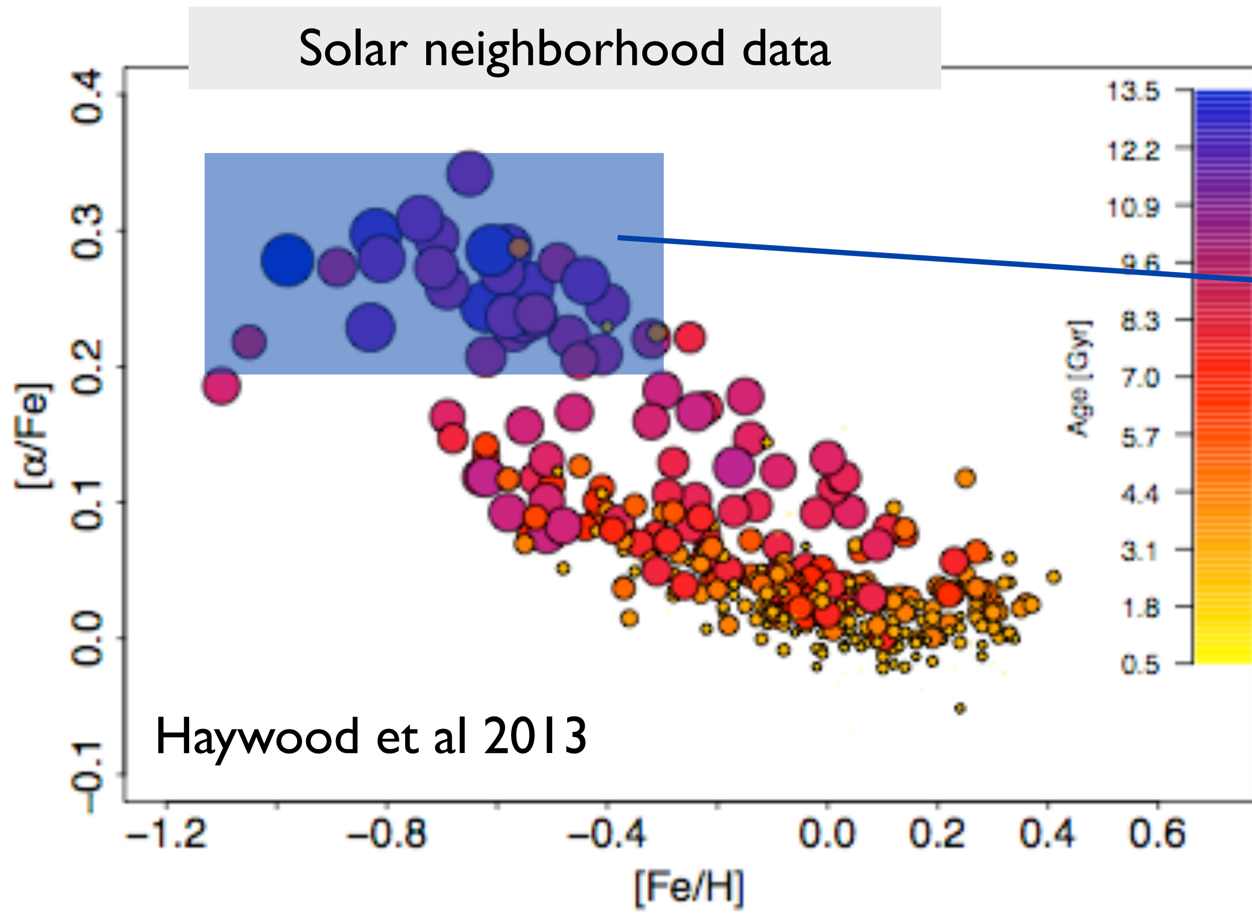
2. The thick disk is massive
   (Snaith et al 2014a,b)

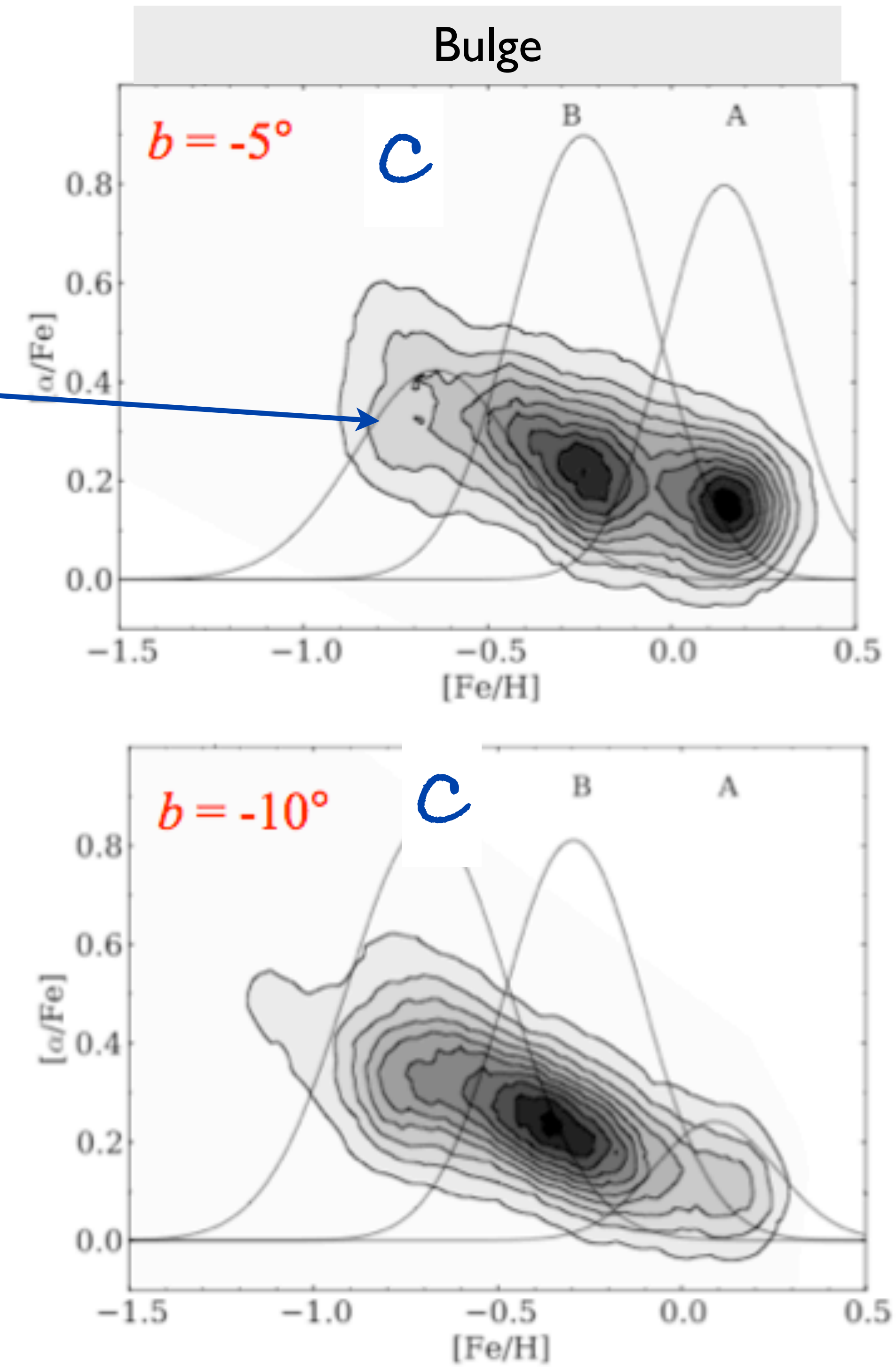
➡ **It must be a major component of the MW inner disk**

3. Moreover, the thick disk at the solar vicinity
and the old, alpha-enhanced, metal poor component in the bulge almost
perfectly overlaps in [alpha/Fe]-[Fe/H] (Gonzalez et al 2011; Bensby et al 2013)

ORIGIN OF POPULATIONS A, B & C:
MAPPING OF A (THIN+THICK) DISK INTO A BOXY BULGE

Di Matteo et al 2014a,b





Ness et al 2013

The MW bulge has a pure (thin+thick) disk origin.
Its stellar components are indistinct from those of the MW disk
(see also discussion in ARGOS papers and N-body (thin+thick) disk models from Bekki & Tsujimoto 2011)

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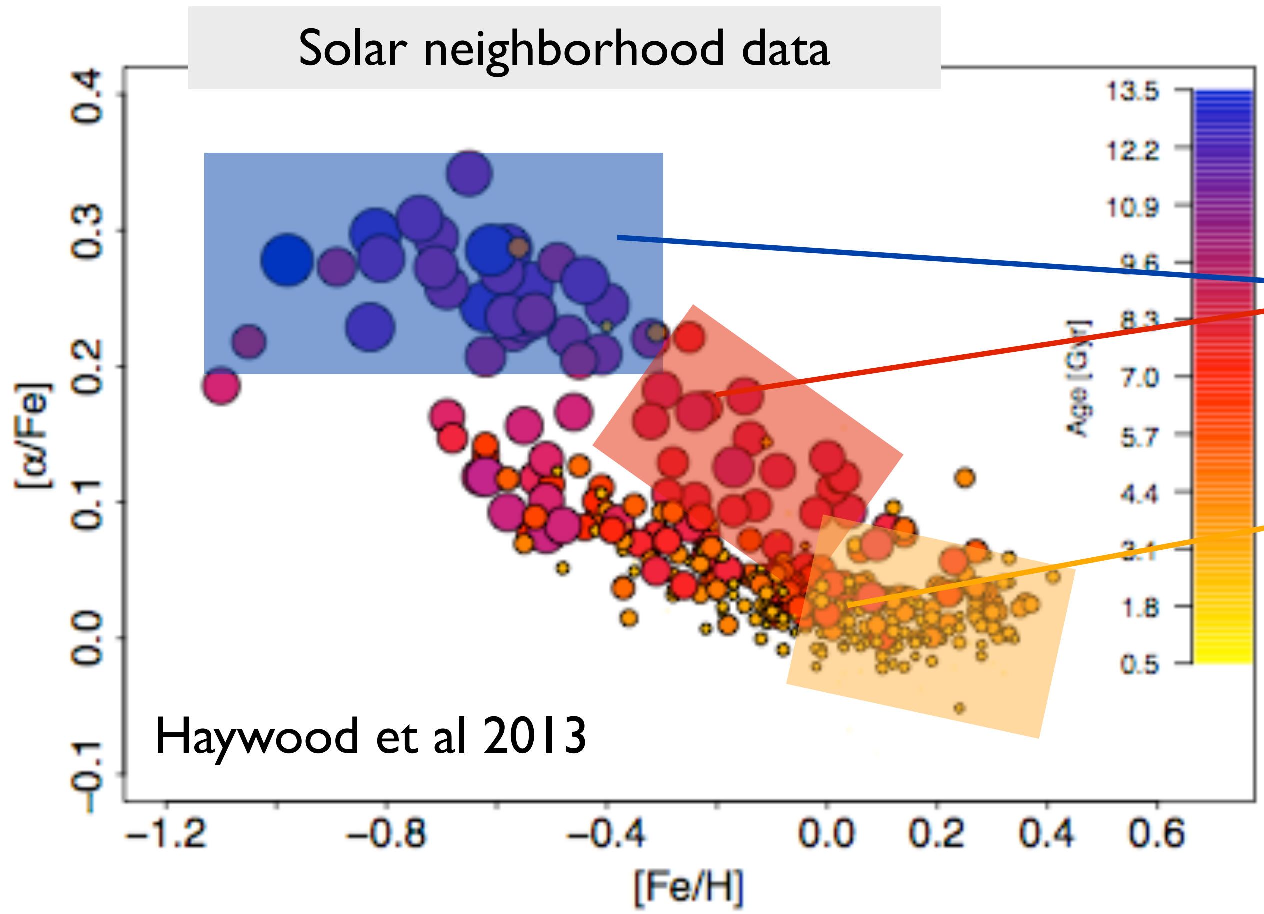

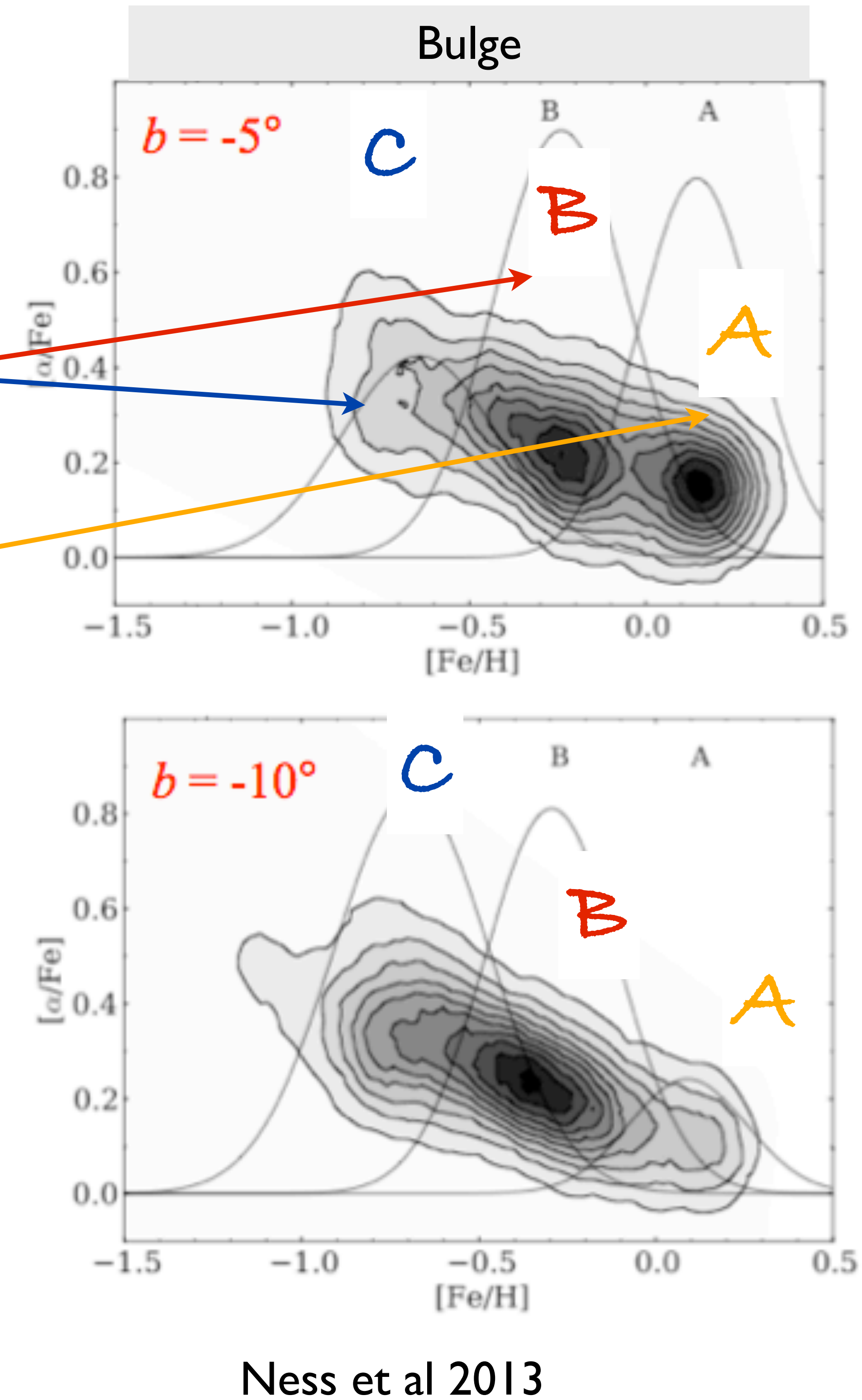

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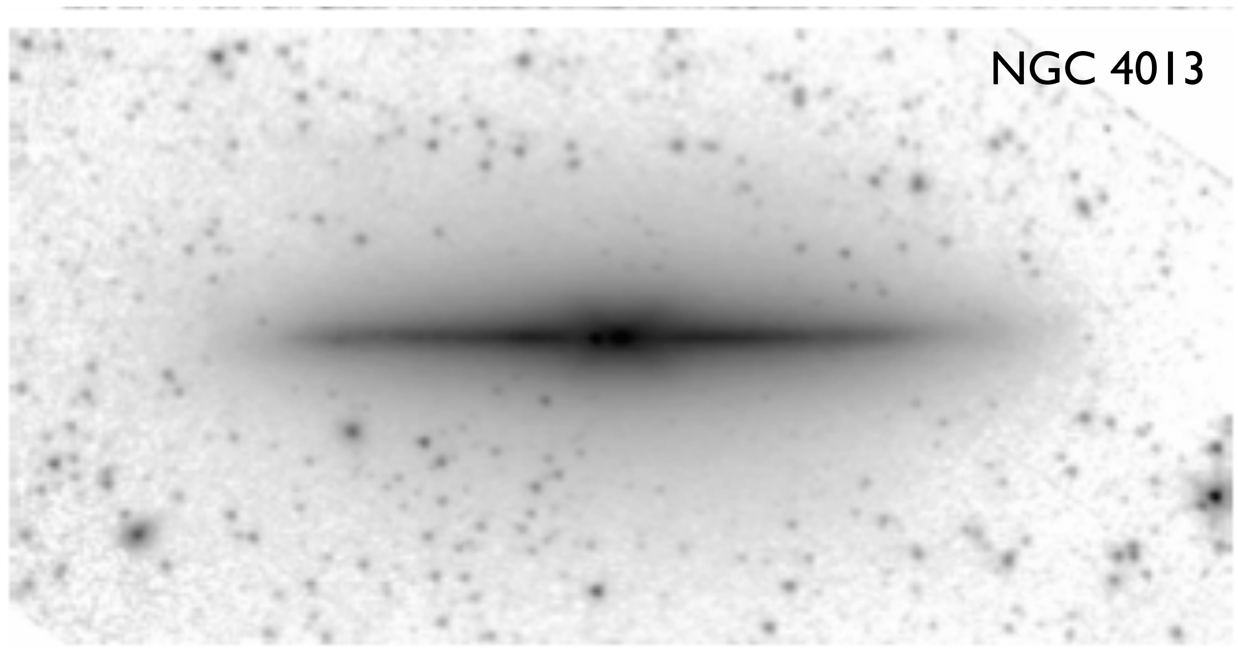
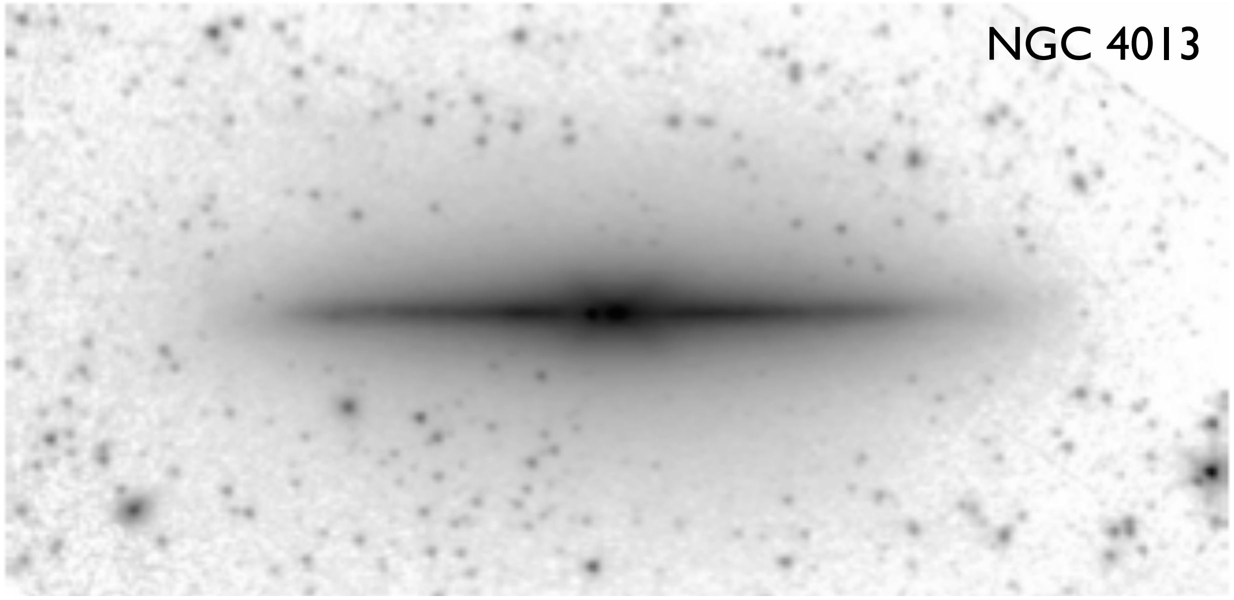
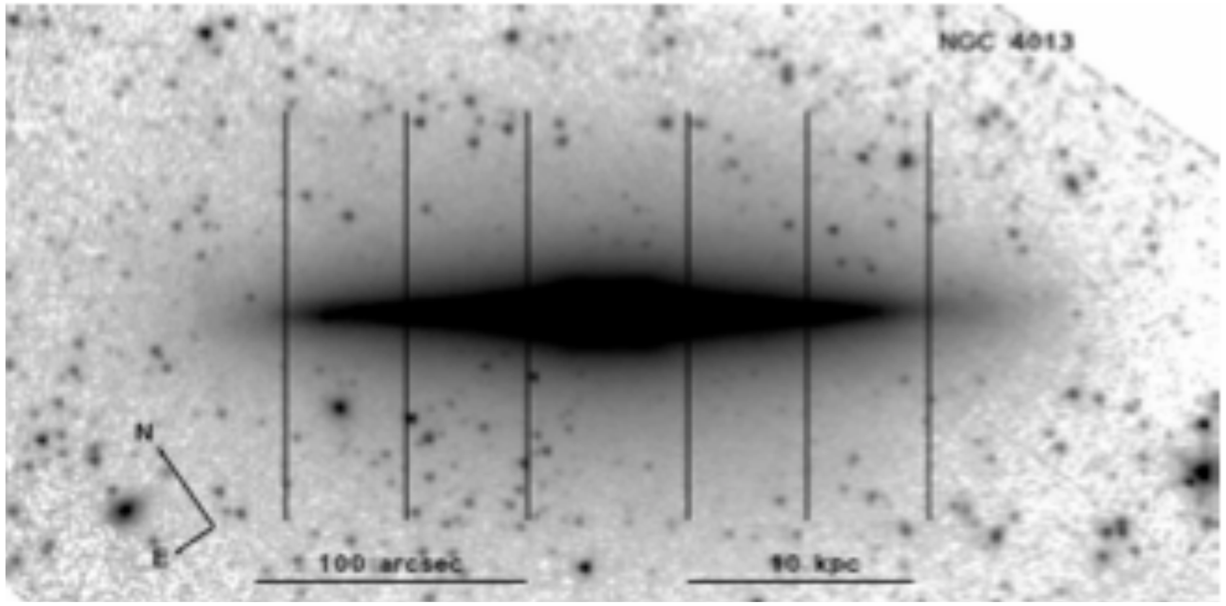
Comeron et al 2011: "THICK DISKS AS LAIR OF MISSING BARYONS"



**The thick disk is a major component of the MW bulge,
and probably of many of the extragalactic boxy/peanut bulges**

Comeron et al 2011: "THICK DISKS AS LAIR OF MISSING BARYONS"





Thick and thin disks
have comparable masses
(see also Comeron et al 2011, 2014, S^4G survey)

The thick disk is a major component of the MW bulge, and probably of many of the extragalactic boxy/peanut bulges

CONCLUSIONS

1. The Galactic thick disk is the main old stellar population in the bulge

2. Young & old thick disks (see M. Haywood's talk yesterday) reflect into the populations B & C as defined by the ARGOS survey

3. Only a very limited or non-existing contribution of a classical spheroid in the MW bulge

Exciting times where **we are witnessing at a change of paradigm** in the study and interpretation of galaxy structure and stellar populations:

➡ the **role of classical bulges in disk galaxies has probably been overestimated**
➡ **thick disks as major relics of the early evolution** of galaxy disks

Both Galactic and extragalactic studies are supporting this new vision.
One of the main challenges for galaxy evolution studies in the coming years.