Stellar populations in the Galactic Bulge

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- Two main scenarios for the bulge formation

  - Gravitational collapse or hierarchical merging of subclumps

  → quick formation at early times → alpha-enhancement

  → ellipsoidal shape

  → isotropic velocity distribution

  - Secular evolution of the Galactic disc

  → slow formation from disc instability (bar)

  → boxy/peanut shape

  → bar driven kinematics

Presentation

1. Structure
2. Metallicity
3. Kinematics
4. Abundances
5. Ages

A bar in the Galactic disc

2MASS atlas image

First suggested by de Vaucouleurs (1964), confirmed by:

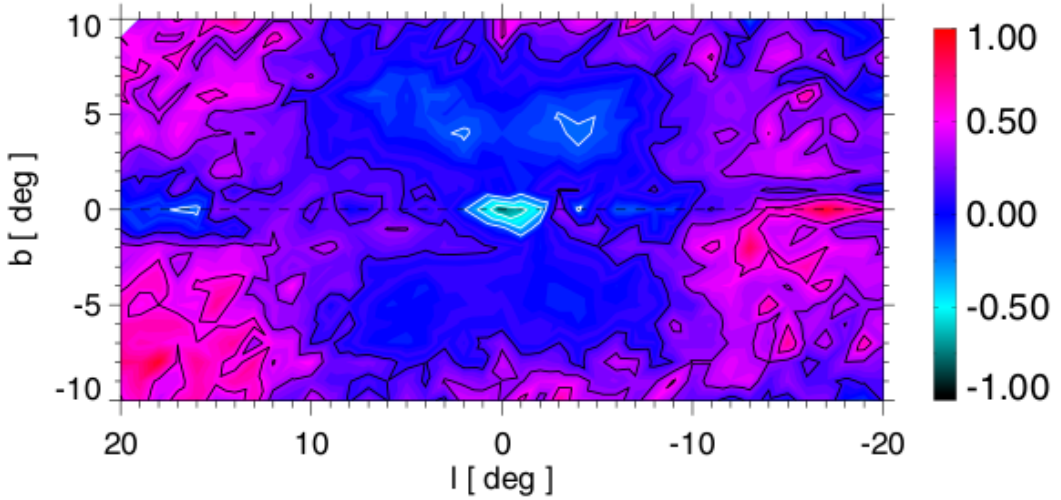
- ✓ Gas kinematics
- ✓ Infrared luminosity distribution — COBE
- ✓ Star counts — IRAS, DENIS, 2MASS, ISOGAL
- ✓ Microlensing — MACHO, OGLE, EROS
- ✓ Stellar kinematics — SiO masers, OH/IR, low Av windows
- ✓ Red clump stars — OGLE, near-IR

A single simple structure is not enough...

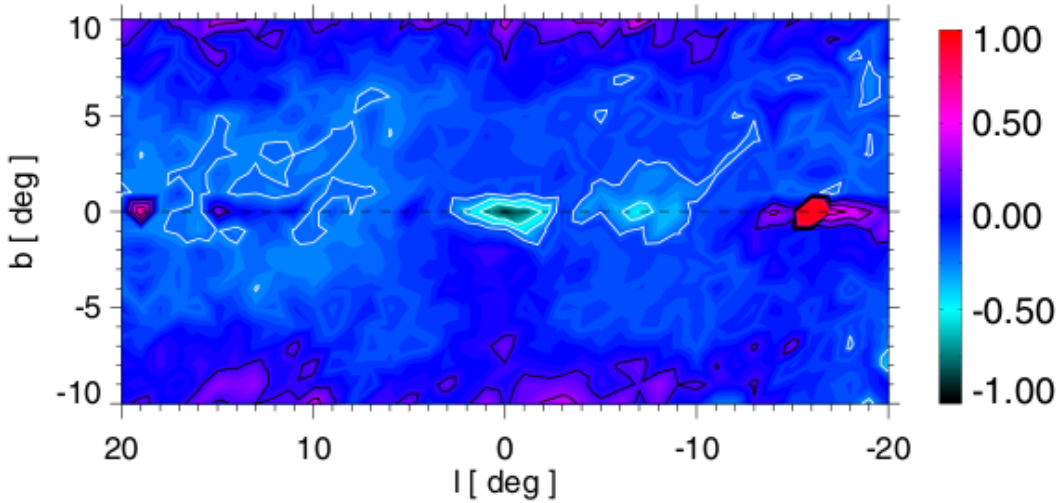
Besançon model Versus 2MASS

$\frac{Nmod-Nobs}{Nobs}$

triaxial boxy shape
φ=13°



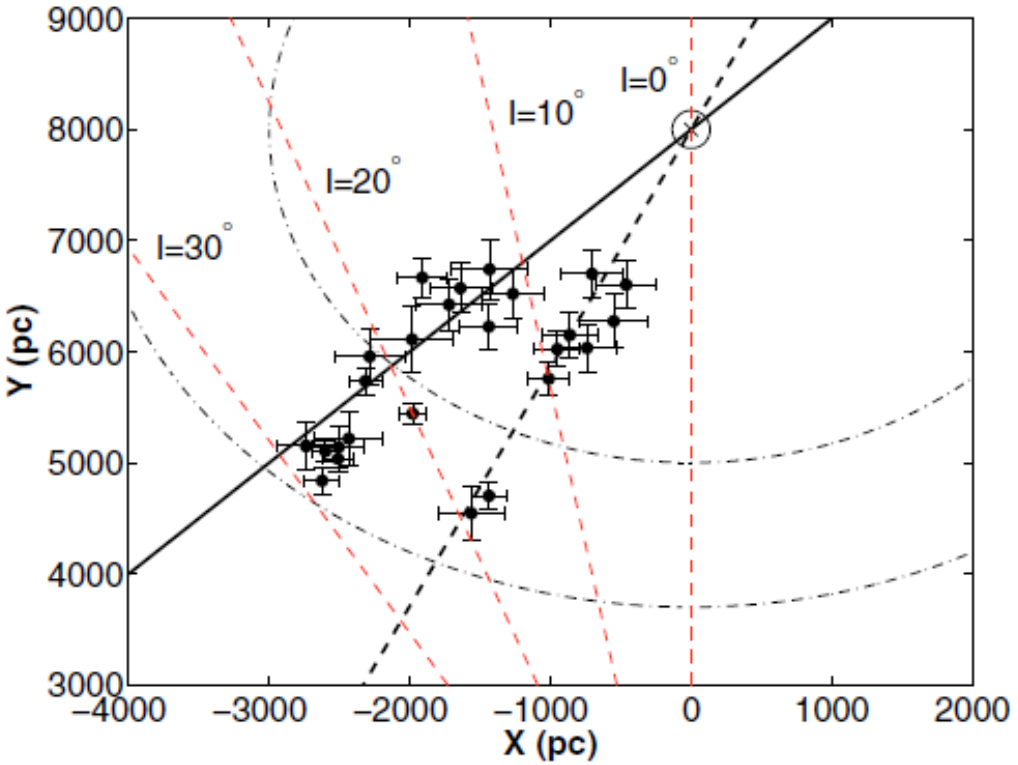
triaxial boxy shape
+
longer and thicker ellipsoid



Robin et al. 2012

Several structures in the plane...

✓ Thin long bar : $10° < |l| < 27°$



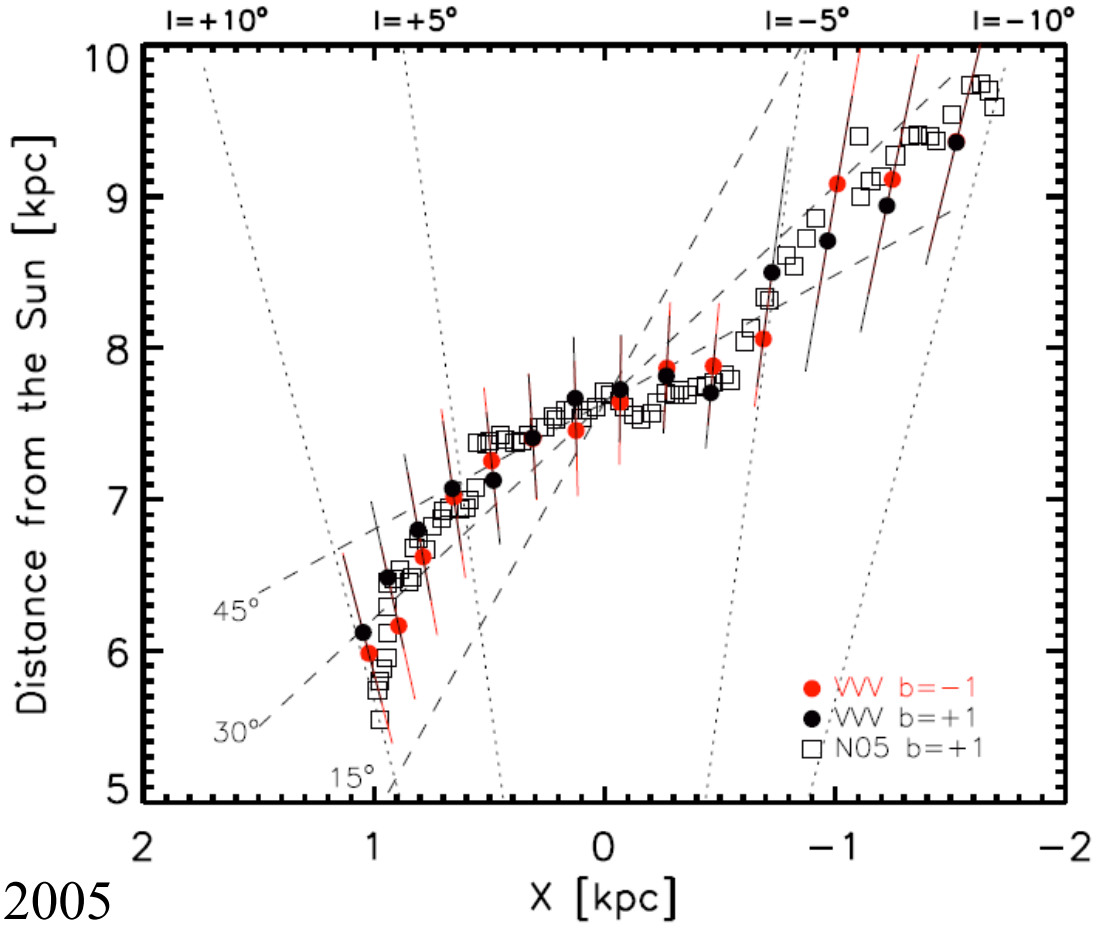
$\varphi_{bar} = 45°$

$\varphi_{bar} = 25°$

Cabrera-Lavers et al. 2008

Several structures in the plane...

- ✓ Inner Bulge: |l| < 4° (R < 0.6 kpc)
- ✓ Main bar : |l| < 10° (R < 3 kpc)

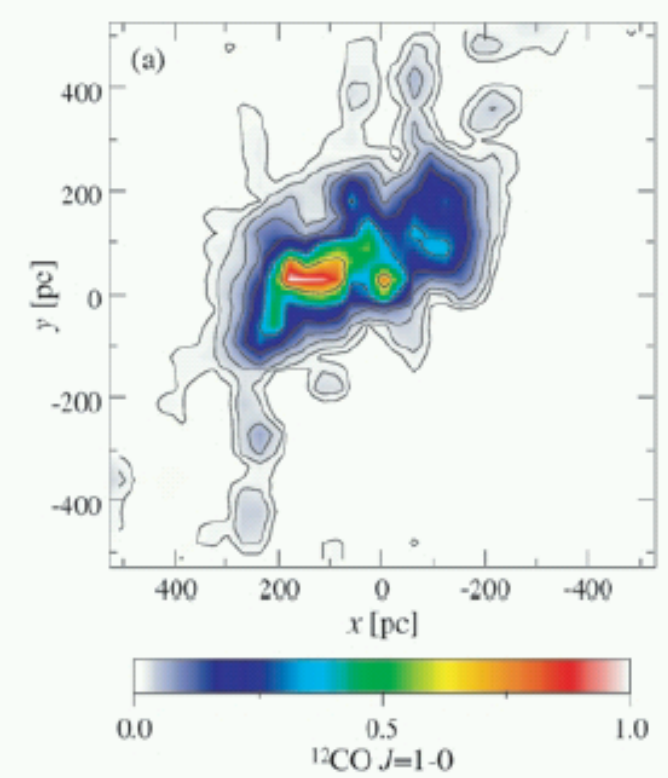


Nishiyama et al. 2005

Gonzalez et al. 2011

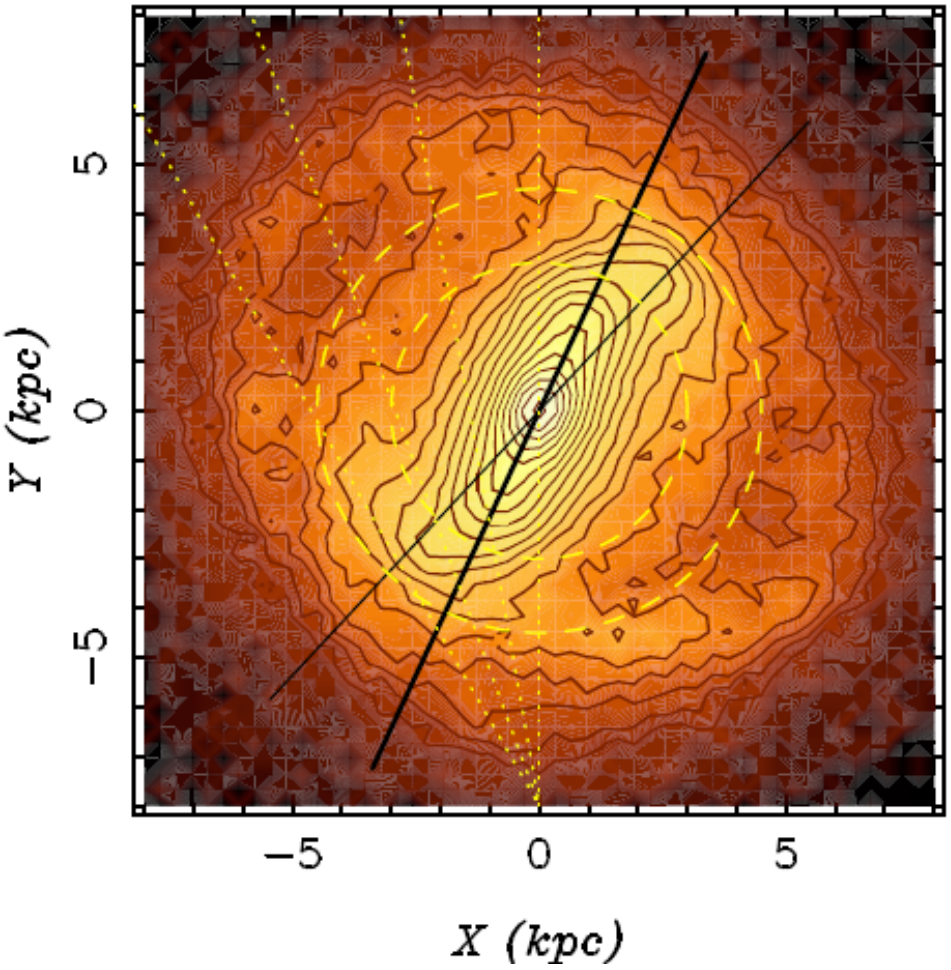
Several structures in the plane...

- ✓ Central molecular zone: |l| < 1.5°, |b|<0.5° (R < 200 pc)
  - ✓ Asymmetry found by Alard 2001 *(2MASS star counts)*
  - ✓ and Sawada et al. 2004 *(CO map)*

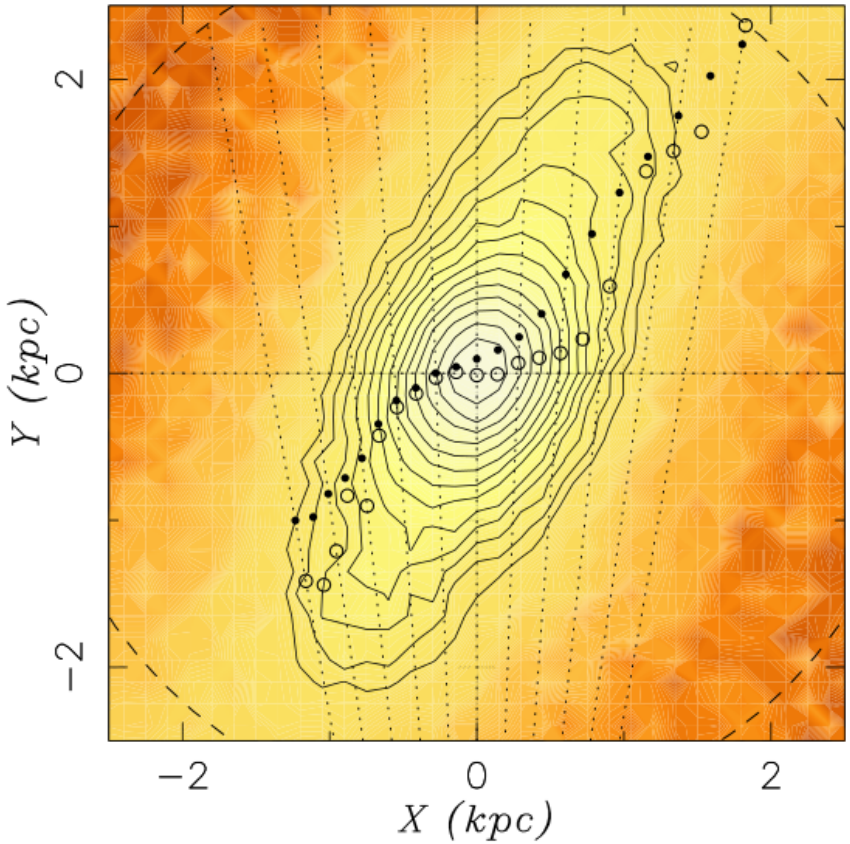


A single dynamical model ?

✓ Reproduce the red clump mean positions at all longitudes...



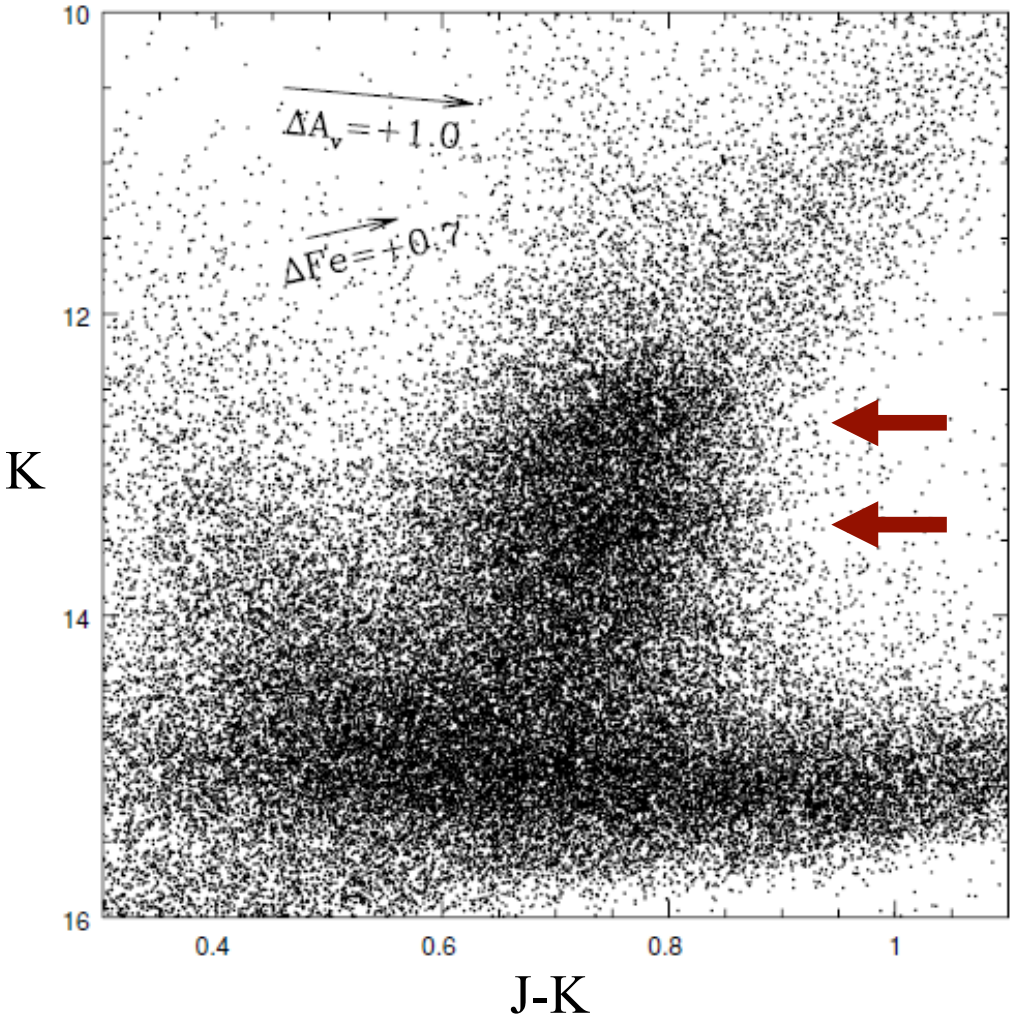
Martinez-Valpuesta & Gerhard 2011

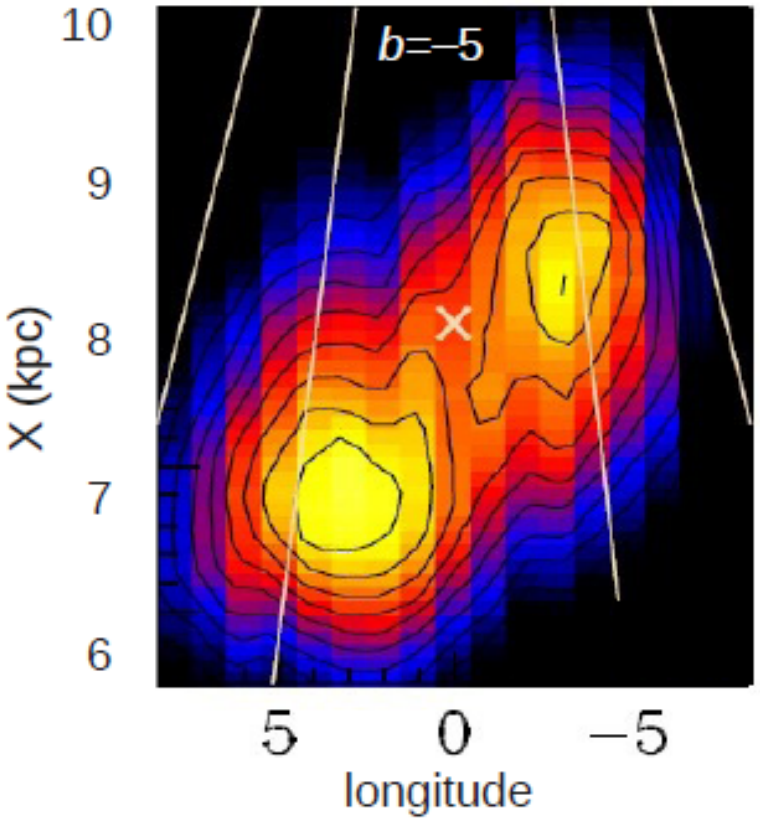


Gerhard & Martinez-Valpuesta 2012

An X-shaped bulge

2MASS l=-1, b =-8



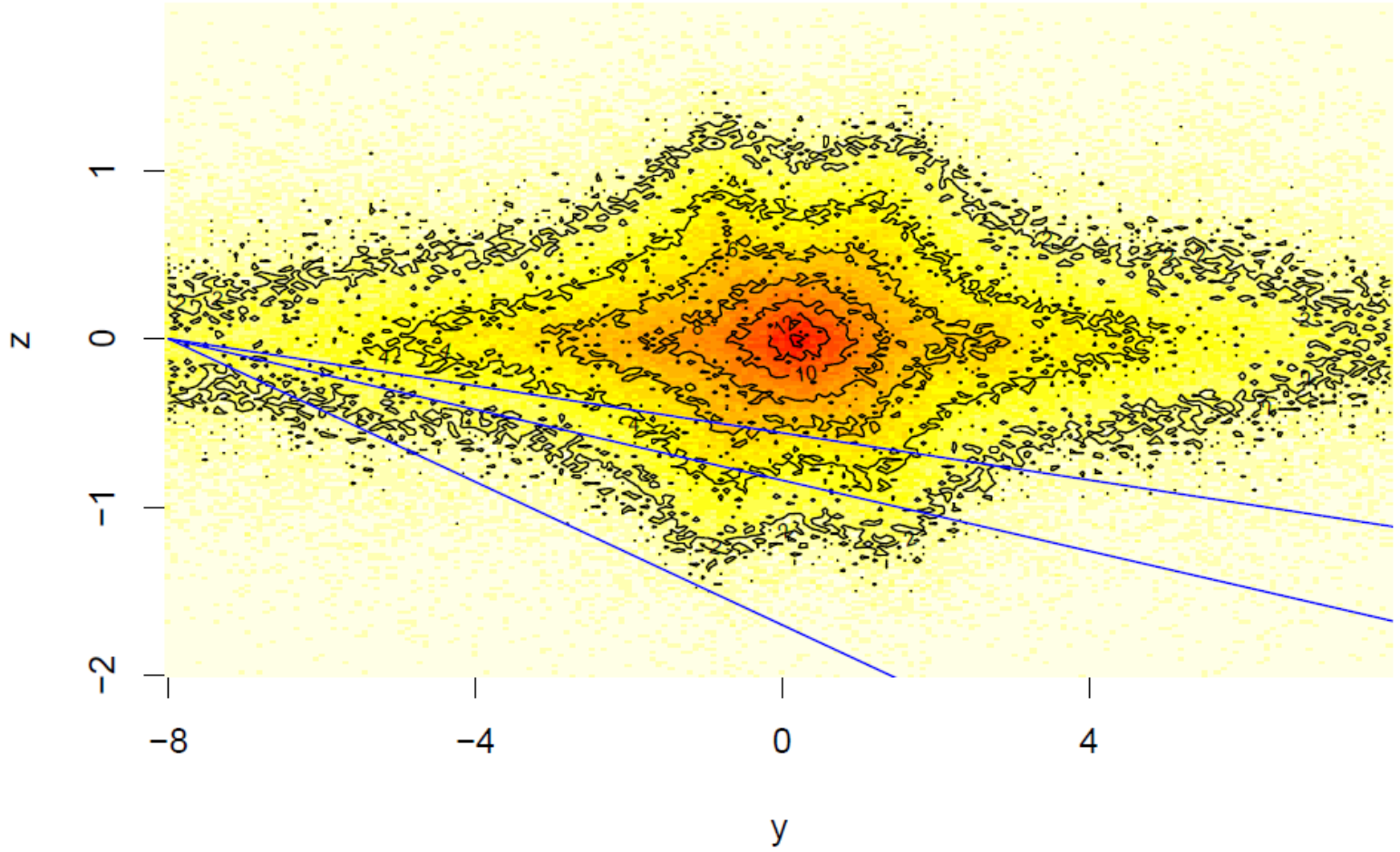


McWilliam & Zoccali 2010, Nataf et al. 2010

Saito et al. 2011

An X-shaped bulge

- X-shape predicted by N-body models, e.g. the Fux 99 model



1. Structure

2. Metallicity

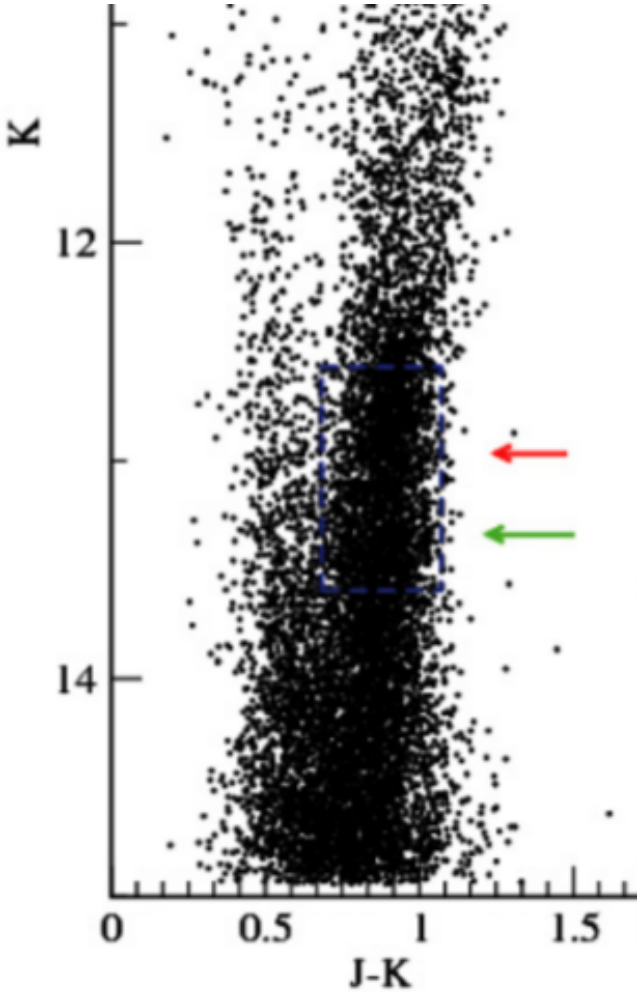
3. Kinematics

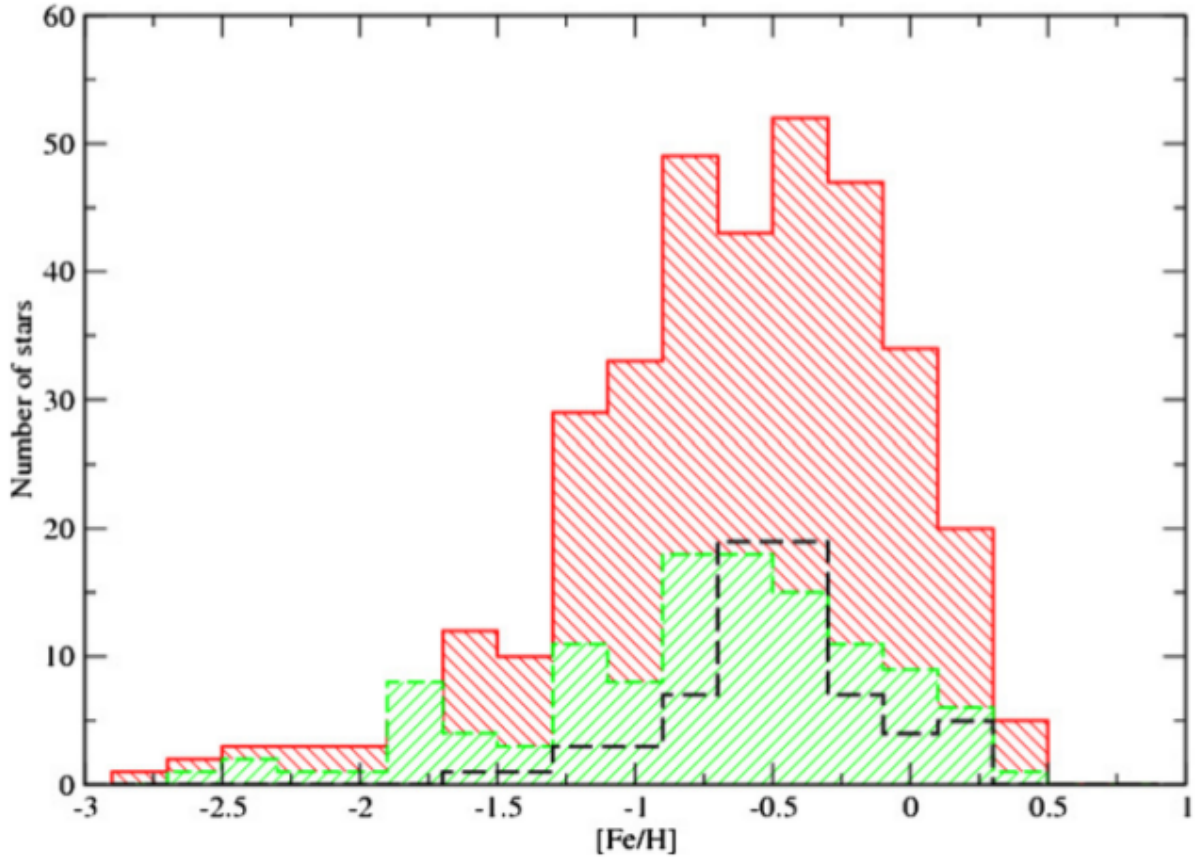
4. Abundances

5. Ages

6. Models

Same metallicity for the double clump ?

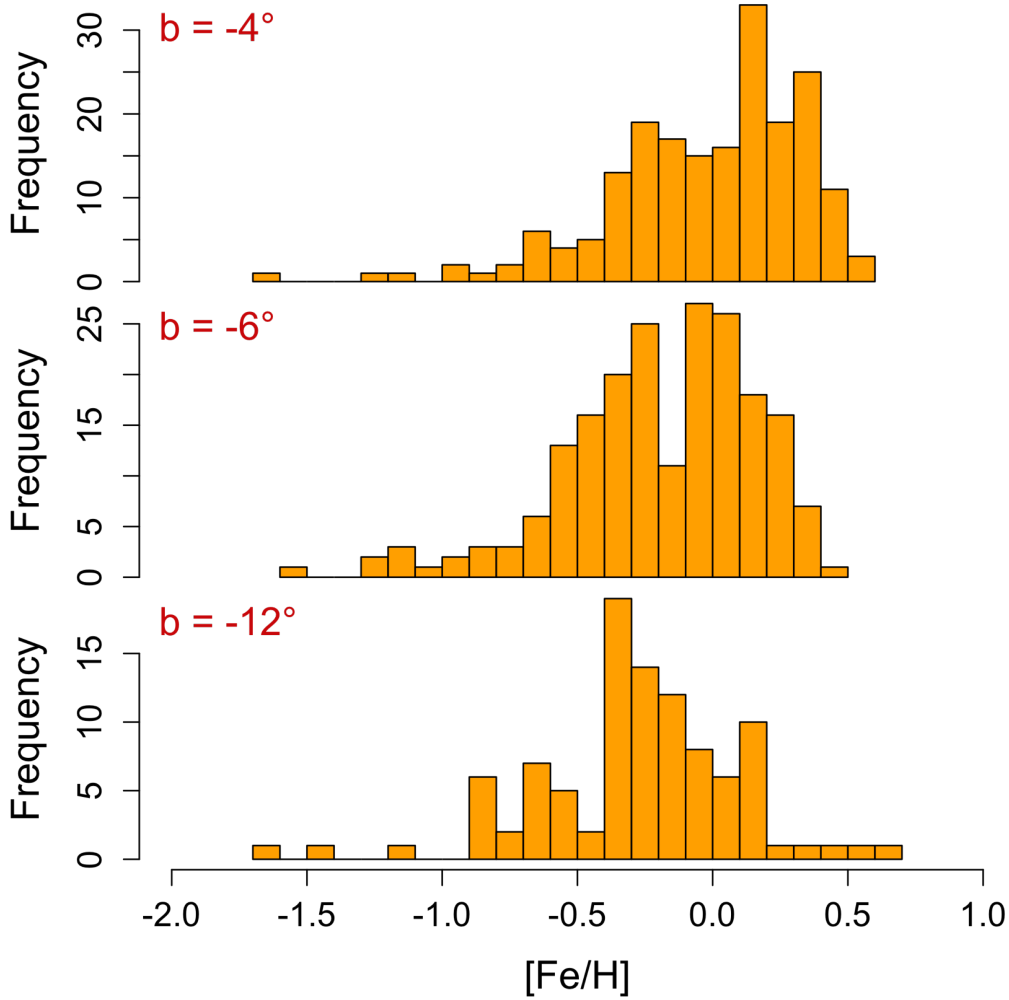




l=0°, b=-8°

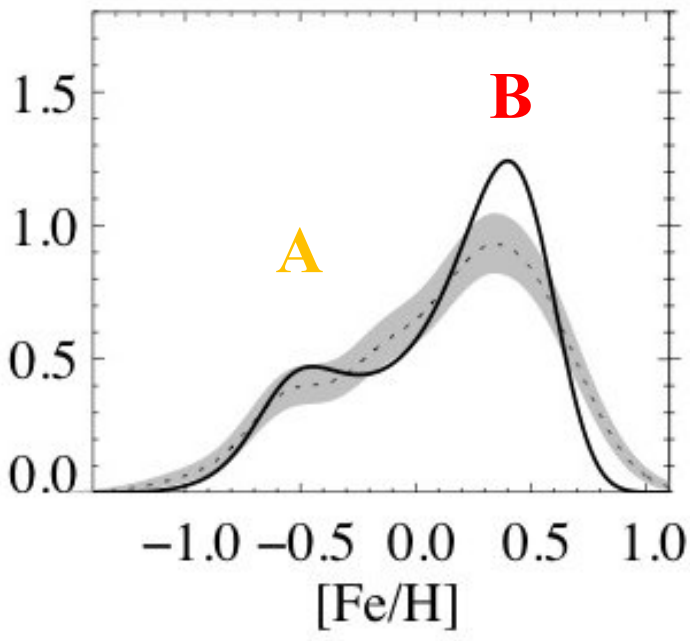
De Propis et al. 2011

A metallicity gradient along the minor axis



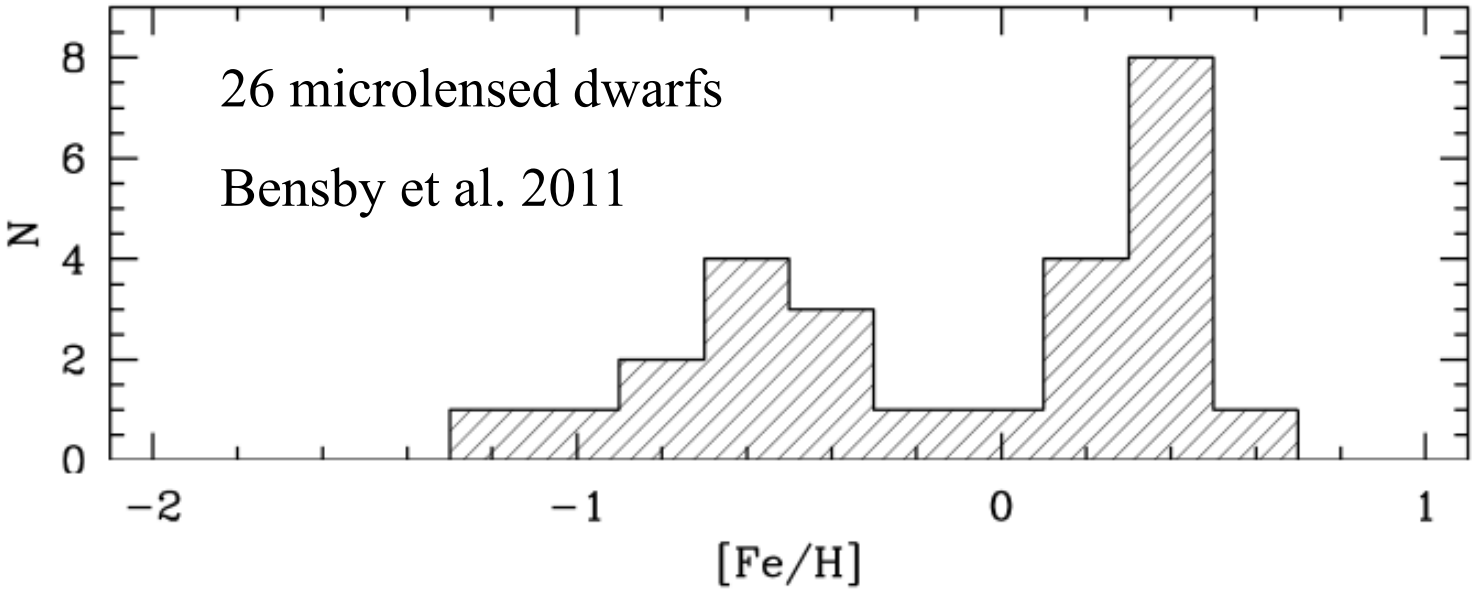
Zoccali et al. 2008

Decomposition of the bulge MDF in two populations



Baade's Window Red Clump Giants

Hill et al. 2011



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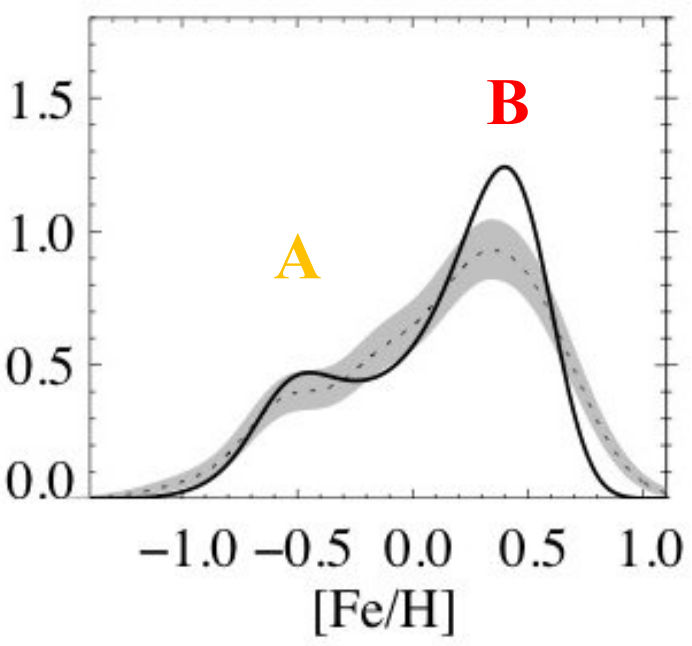
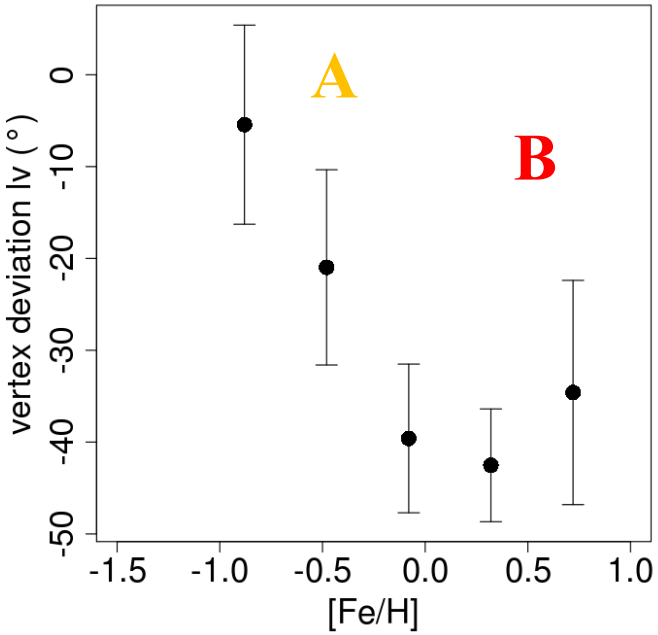
Two populations in Baade's Window



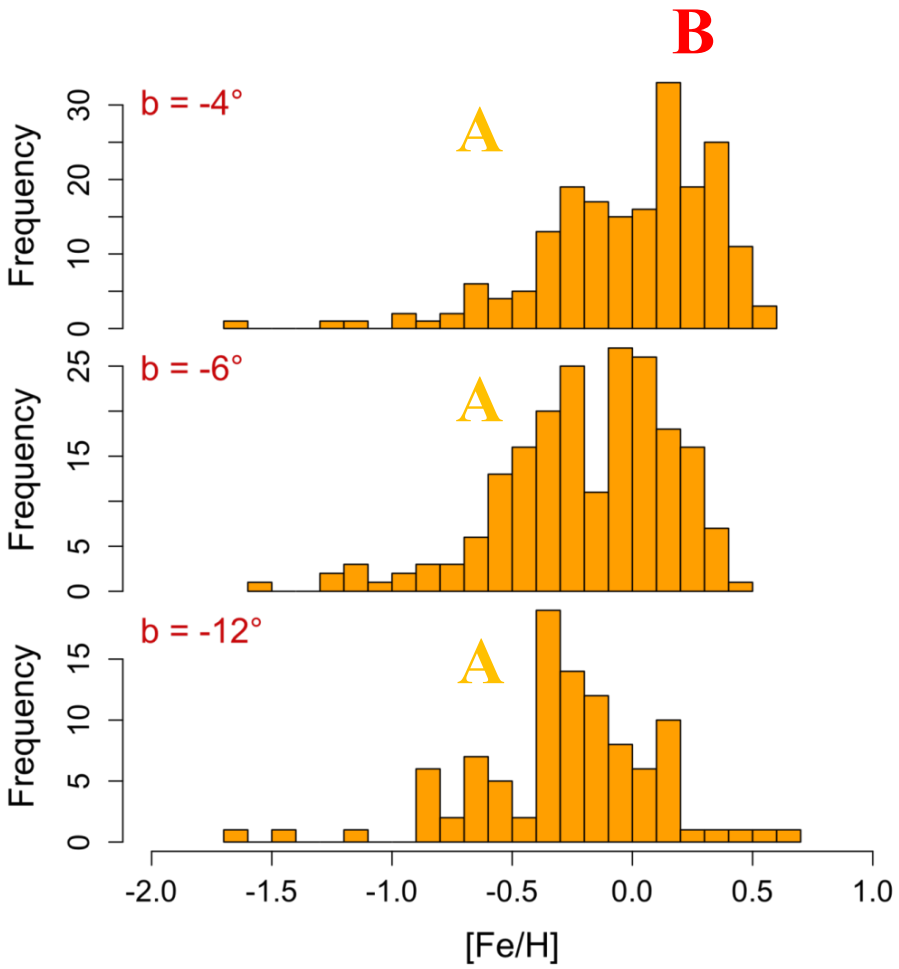
Hill et al. 2011



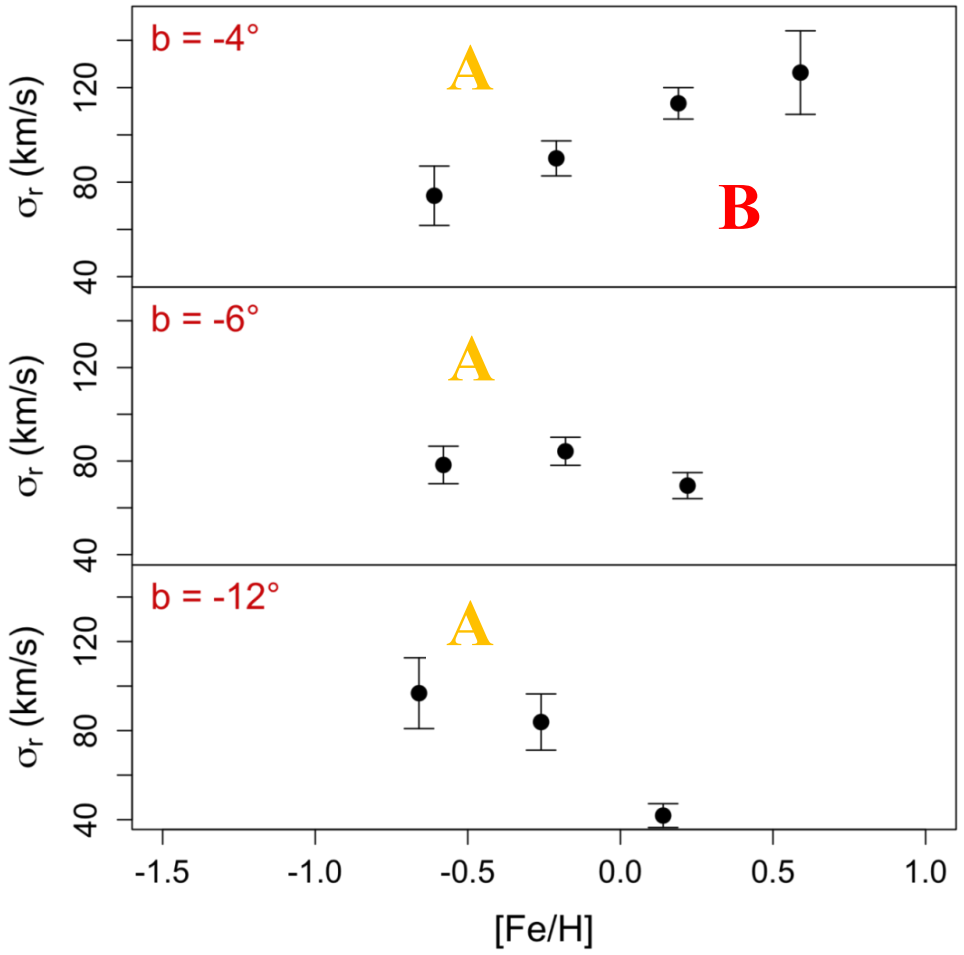
→ metal rich population under the kinematic influence of the bar

Babusiaux et al. 2010

Two populations along the minor axis

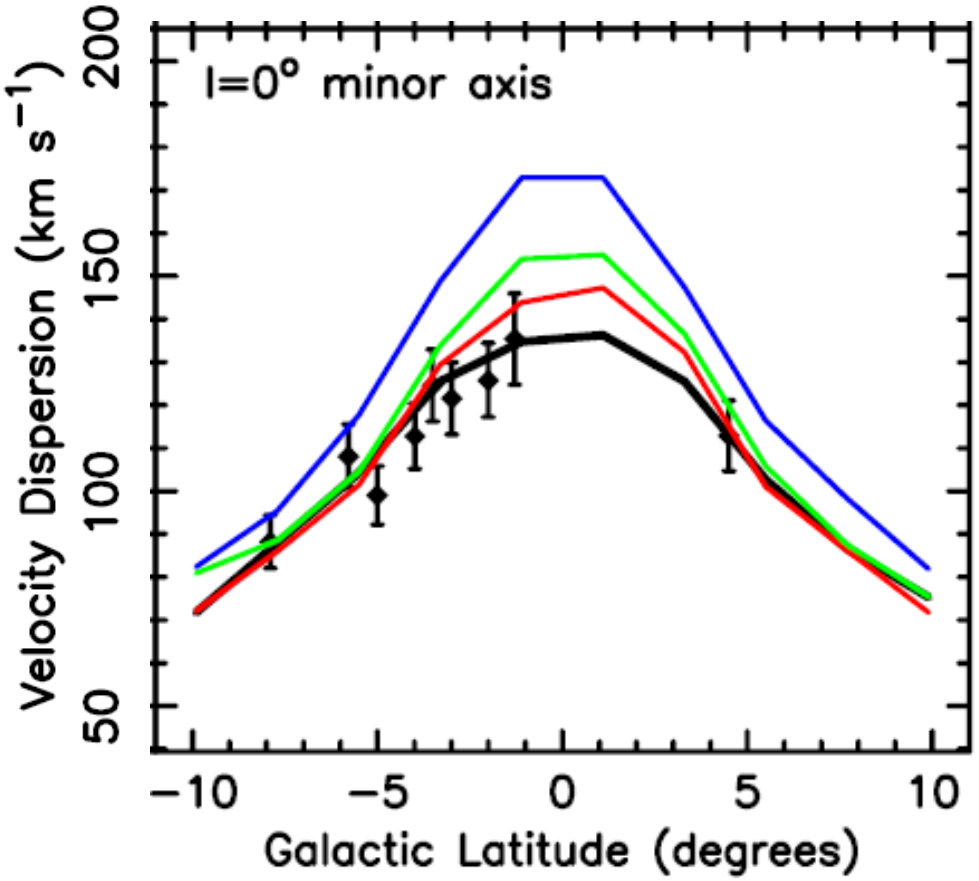


Zoccali et al. 2008



Babusiaux et al. 2010

Cylindrical rotation, consistent with a pure-disc model



$M_{\text{classical bulge}} = 0\ M_{\text{disk}}$

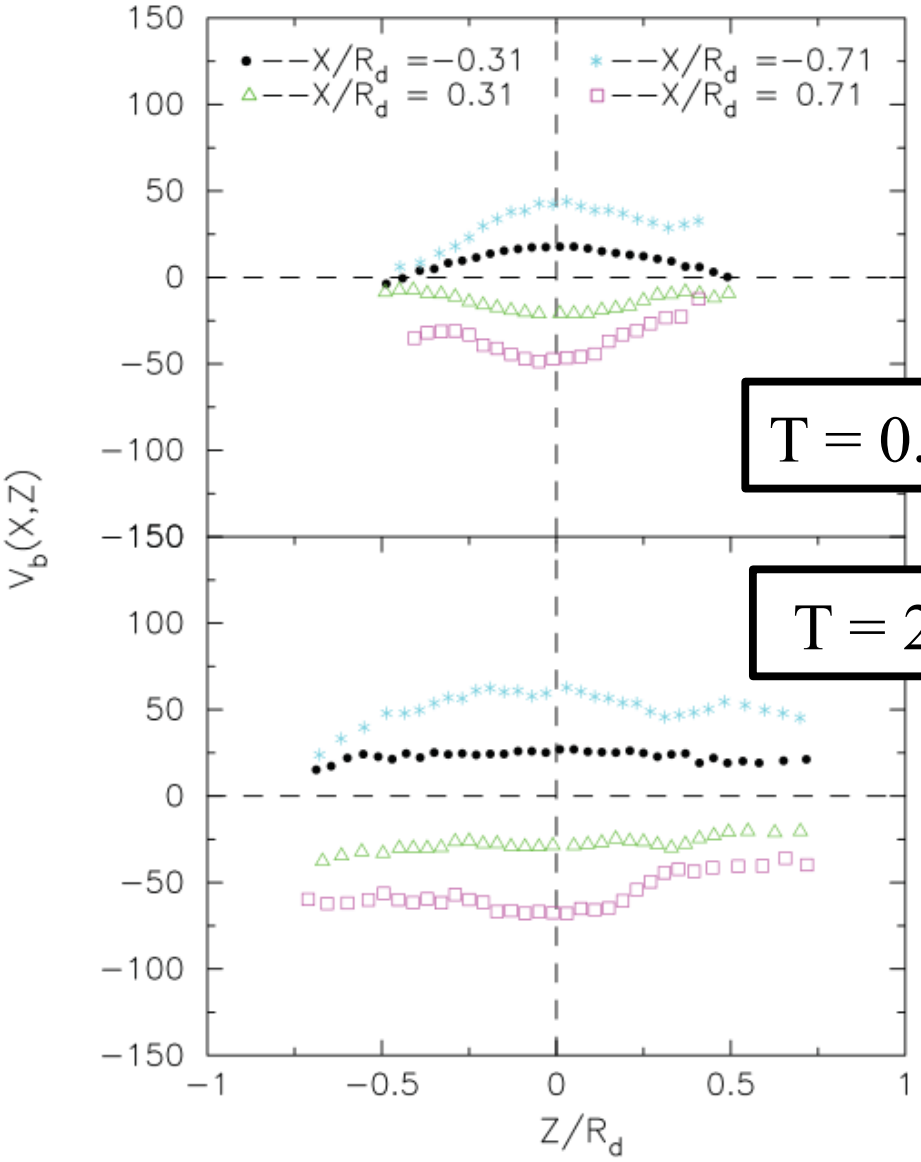
$M_{\text{classical bulge}} = .08\ M_{\text{disk}}$

$M_{\text{classical bulge}} = .15\ M_{\text{disk}}$

$M_{\text{classical bulge}} = .30\ M_{\text{disk}}$

BRAVA survey, Shen et al. 2010

A small classical bulge could stay hidden



T = 0.56 Gyr

T = 2.1 Gyr

Parallel minor-axis velocity profiles of the classical bulge

→ cylindrical rotation develops in the inner region

Saha et al. 2012

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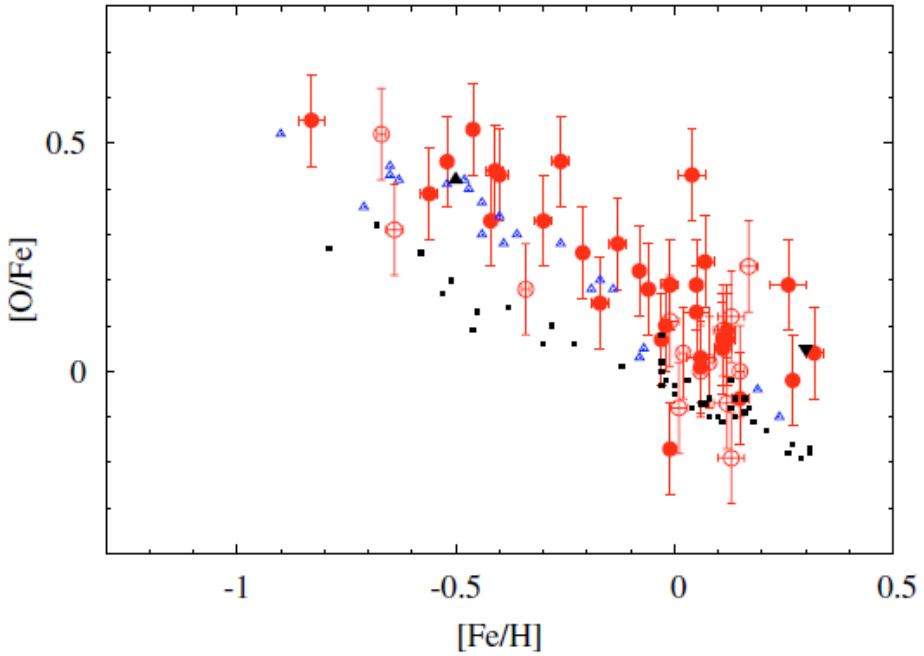
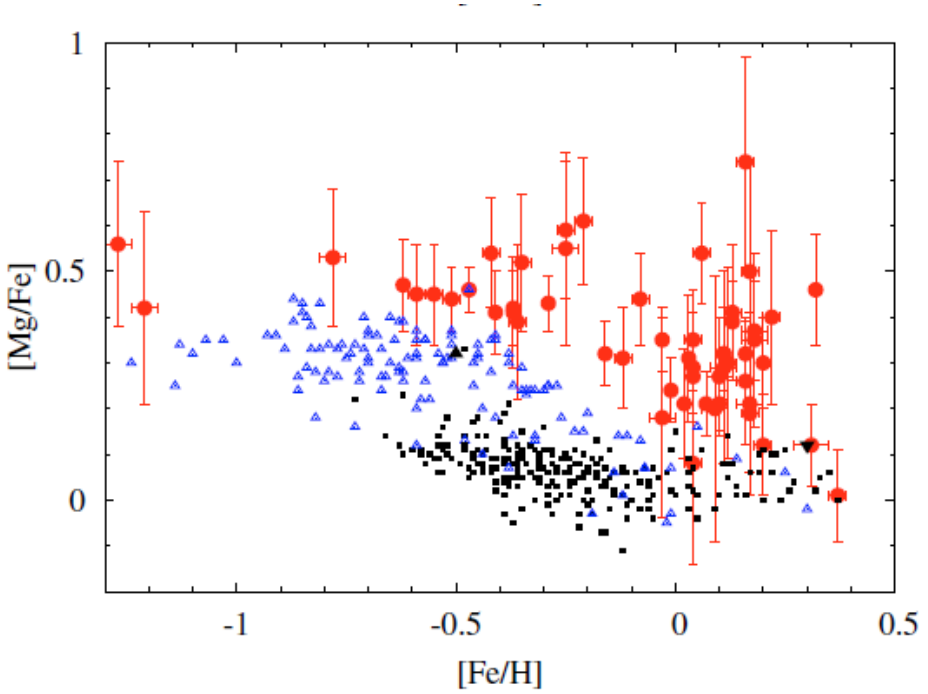
α-elements enhancement

→ short formation time-scale



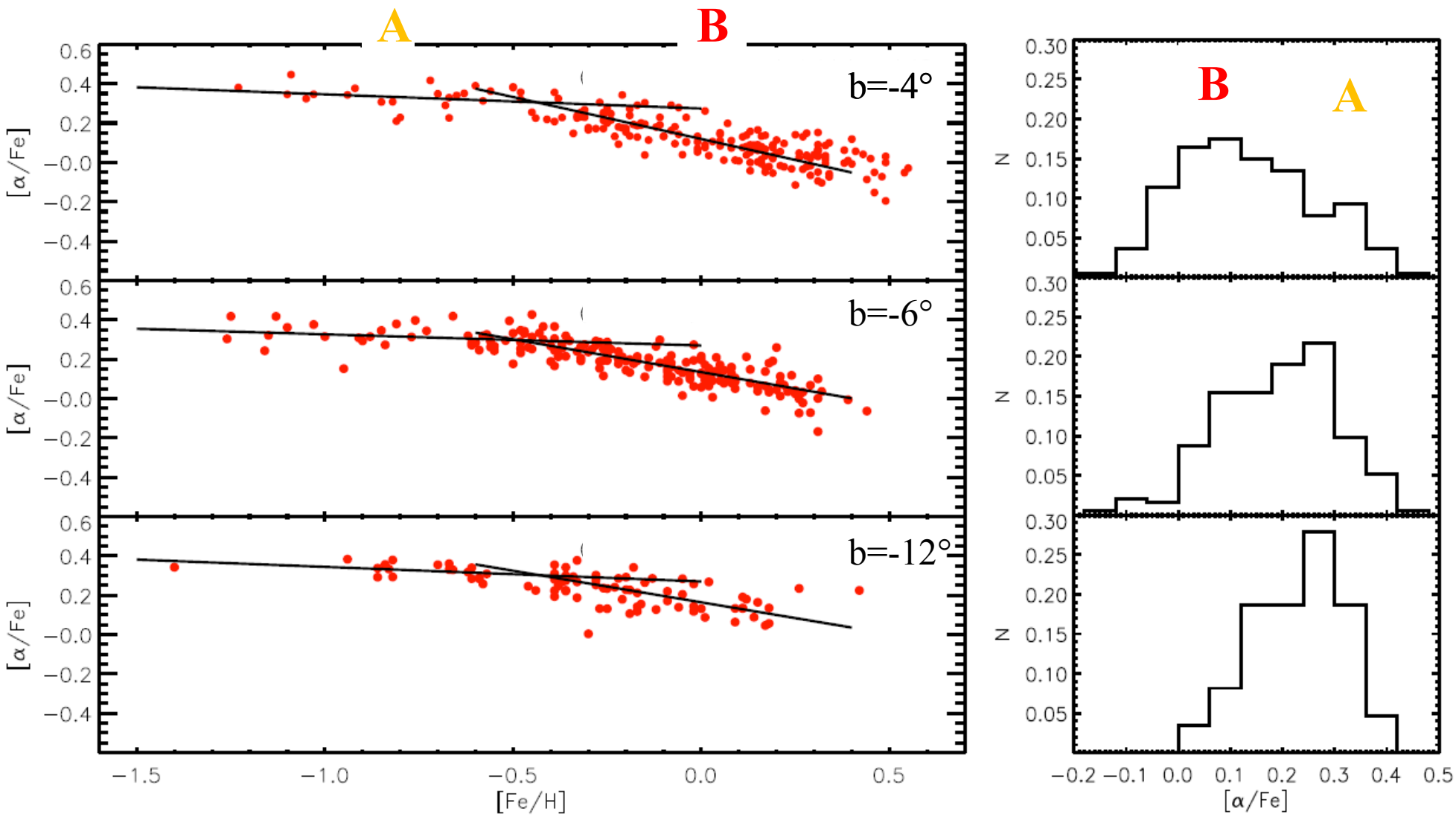
Zoccali et al. 2007



Lecureur et al. 2007

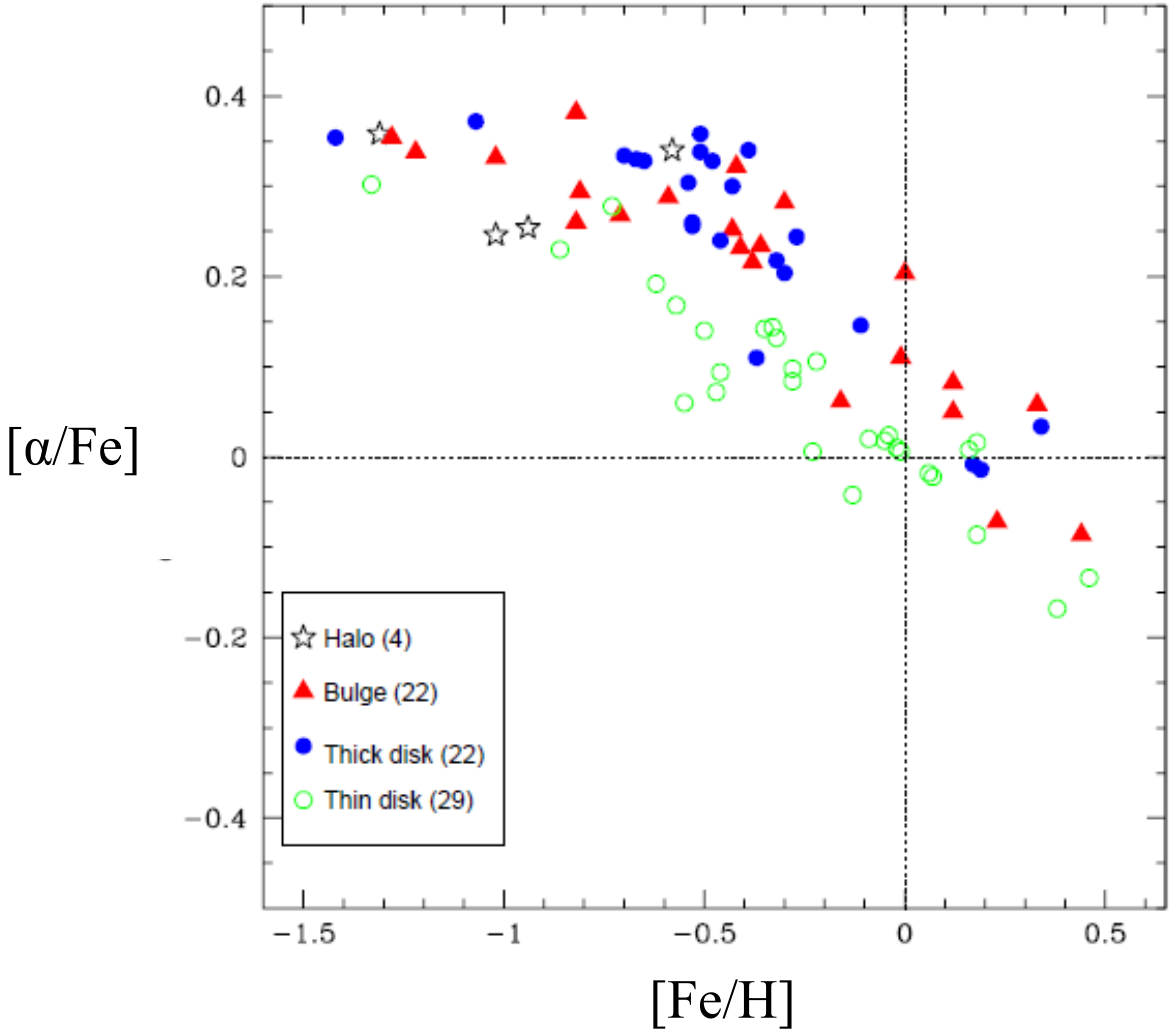
Bulge
Thick disc
Thin disc

Same relation [Fe/H] versus [α/Fe] along the minor axis



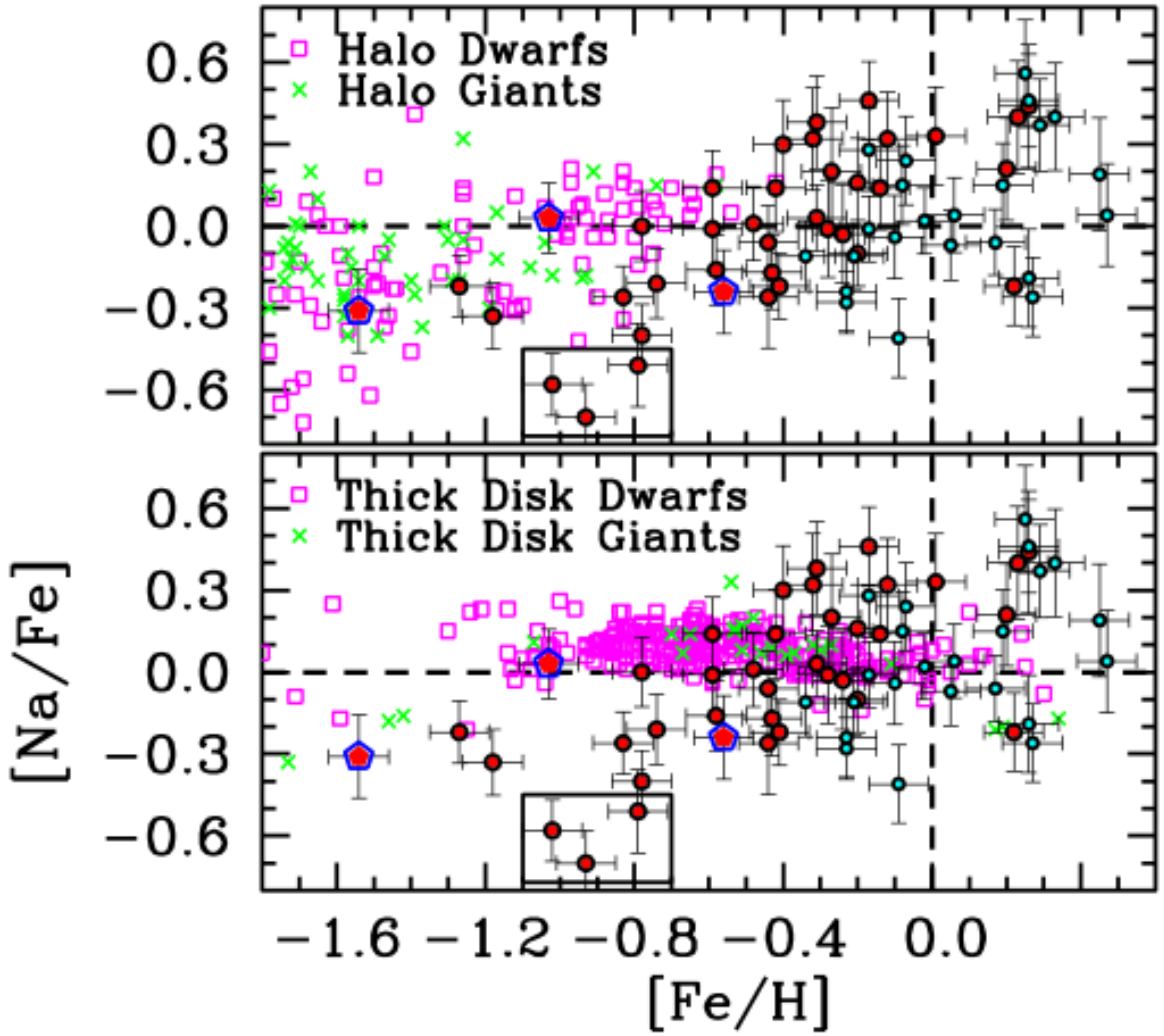
Gonzalez et al. 2011

Similarities Metar poor bulge / Thick disc



Alves-Brito et al. 2010

Similarities Metar poor bulge / Halo



Johnson et al. 2012

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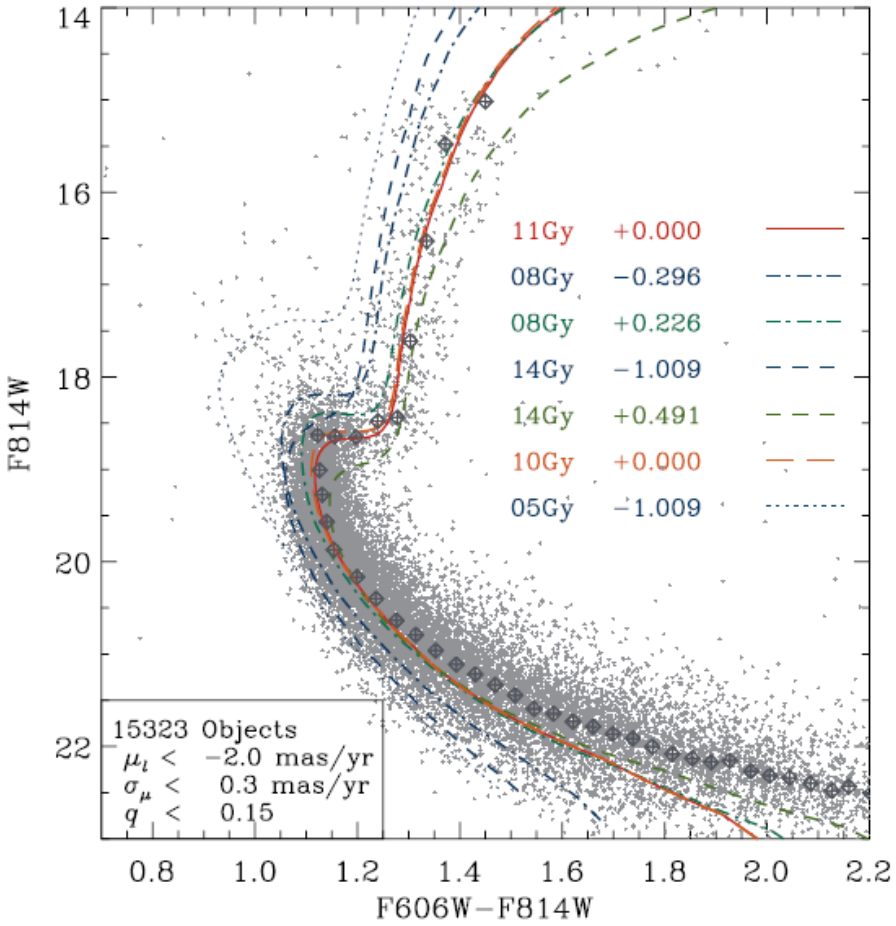
5. Ages

Bulge stars are mainly old (> 10 Gyr)...

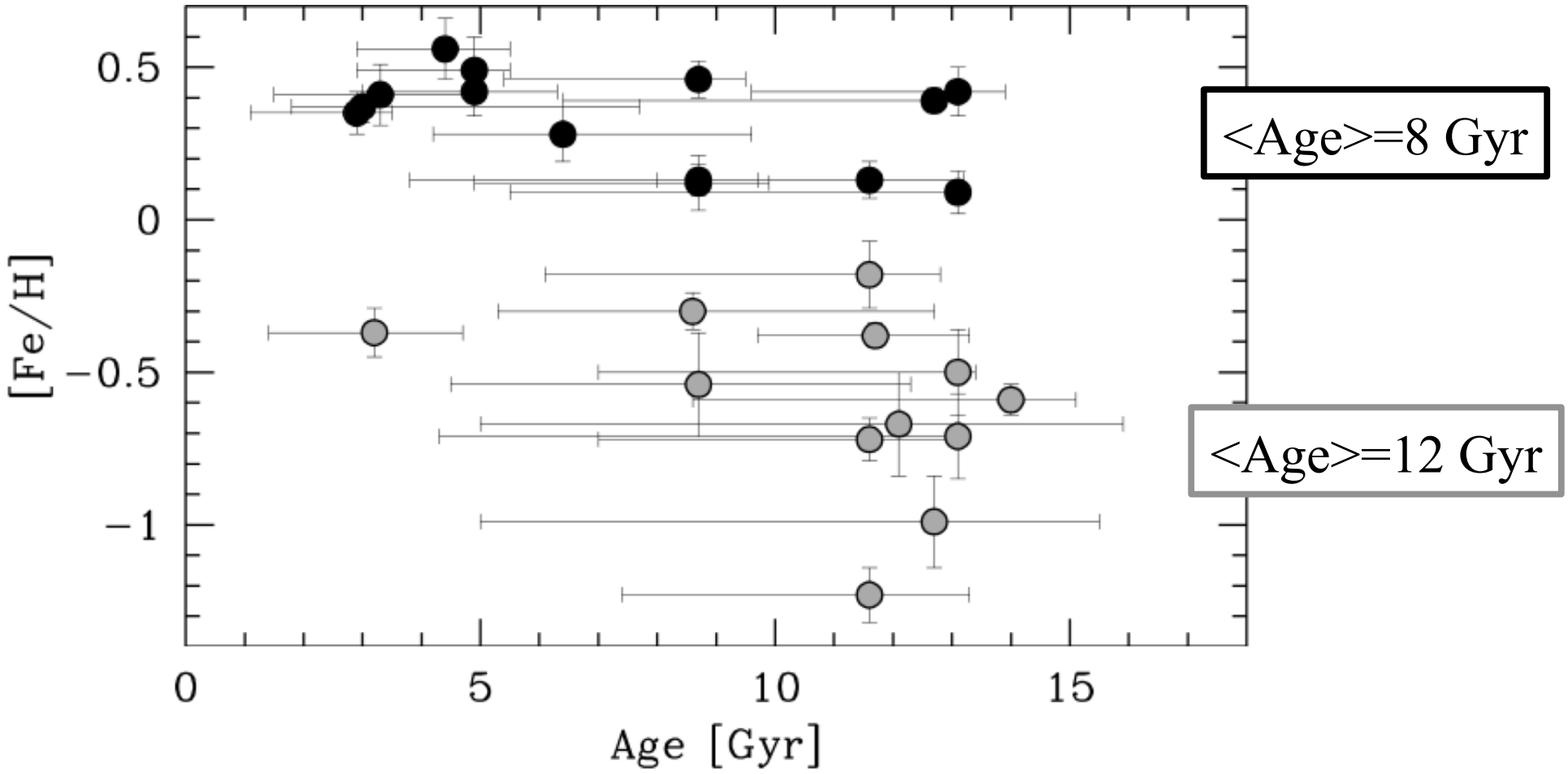


Clarkson et al. 2008

Presence of young and intermediate age populations

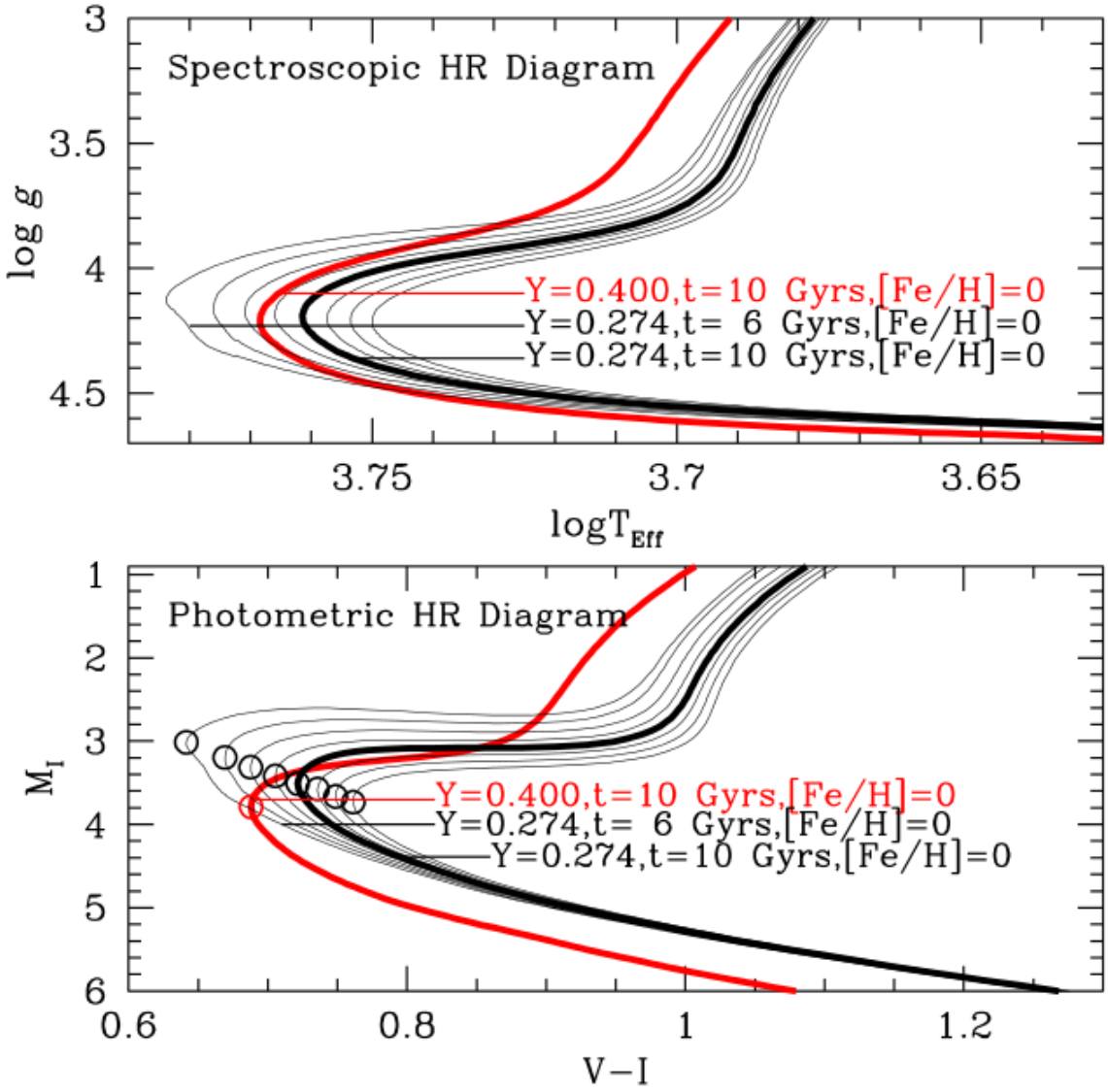
- van Loon et al. 2003 (IR photometry)
- Groenewegen & Blommaert 2005 (Mira stars) 1-3 Gyr up to b=-6°
- Kouzuma & Yamaoka 2009 (LPV) |b|<5

signature of intermediate age microlensed dwarfs



Bensby et al. 2011

Age discrepancy due to enhanced helium enrichment ?



Nataf & Gould 2012

Summary

- Complex structure both along the major axis and the minor axis

- Observational evidences for the presence of two formation scenario

  – Secular evolution

  ← X-shaped peanut, metal-rich component with solar abundances, bar-like kinematics

  – Older population with short formation time-scale

  ← old, metal-poor, enriched in alpha-elements

Perspectives

The Bulge can now be reached by massive surveys !

- Photometric surveys
  - UKIDSS, VISTA VVV (NIR)
  - PanStarrs, Skymapper, VST... (optical)
- Spectroscopic surveys
  - APOGEE
  - AAOMega bulge survey (AAT, PI K. Freeman)
  - Large Program on the bulge (FLAMES, PI M. Zoccali)
  - VLT Public Survey (FLAMES, PI G. Gilmore)
- Gaia !