# THE GALACTIC BULGE: HIGH-RES MOS

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# Outline:

- Interest of studies on Galactic bulge
- Data available on metallicity, kinematics
  in field bulge stars
- More recent evidence: X-shape bulge; He-rich?
- Metal-poor globular clusters in the inner bulge

**VLT → E(B)-ELT**

# Galactic bulge:

- Template for stellar populations in Ellipticals and bulge of spirals
- Spectra provide metallicity, kinematics
  - field and globular clusters
- → Formation of the bulge: secular evolution or classical scenario, or satellite accretion
- More recent evidence:

  X-shape bulge; He-enrichment

  Chemical enrichment by massive spinstars

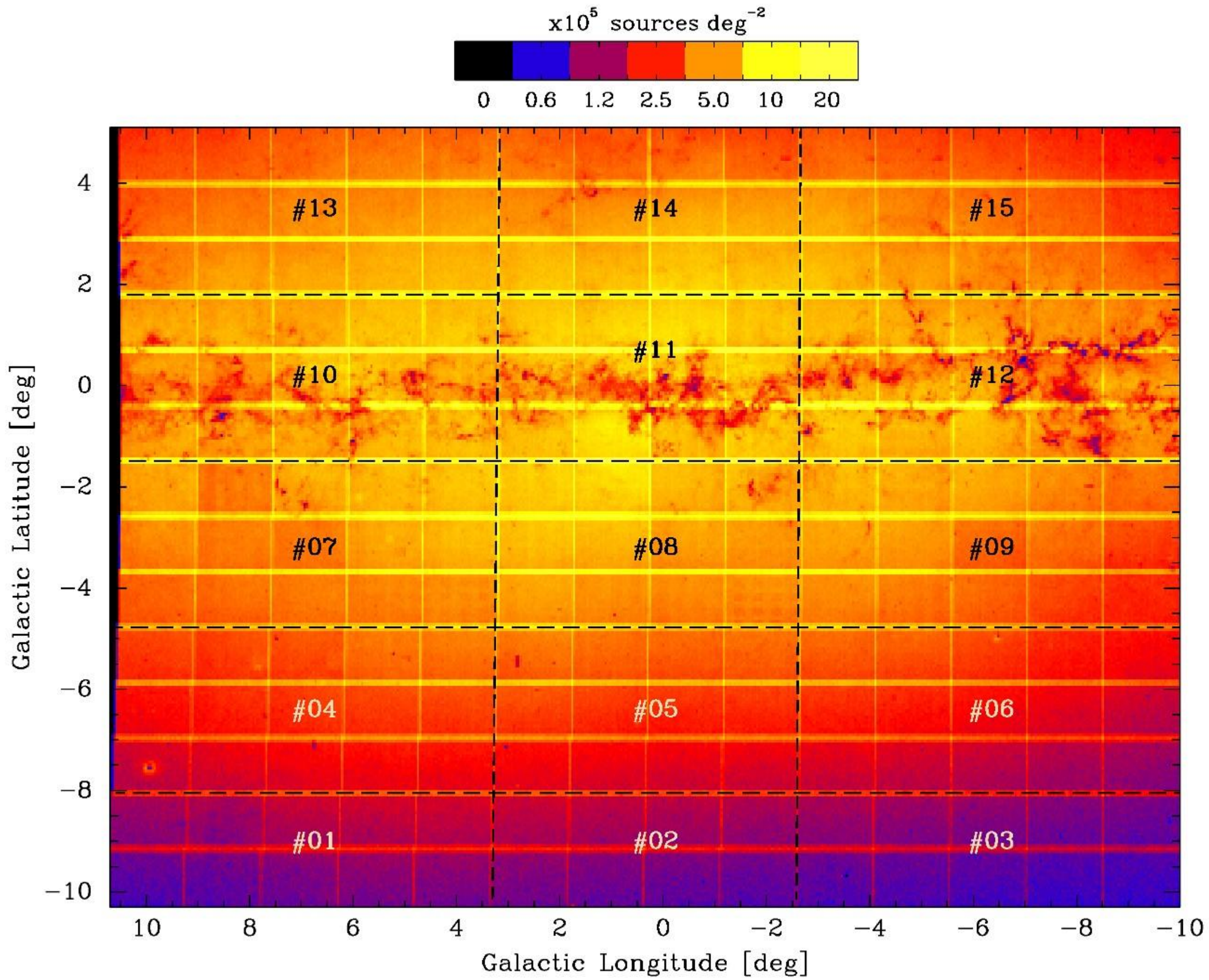
# VVV: The VISTA Variables in the Via Láctea

DR1: http://archive.eso.org/cms/eso-data/eso-data-products (Saito et al. 2012)

- **300 $deg^2$ bulge**: $-10° < l < +10°$ $-10° < b < +5°$ (Minniti et al. 2010)
- **220 $deg^2$ disk**: $295° < l < 350°$ $-2° < b < +2°$

- Y, Z, J, H, Ks filters – ~4mag deeper than 2MASS
- **~100 epochs in Ks – variability campaign started**

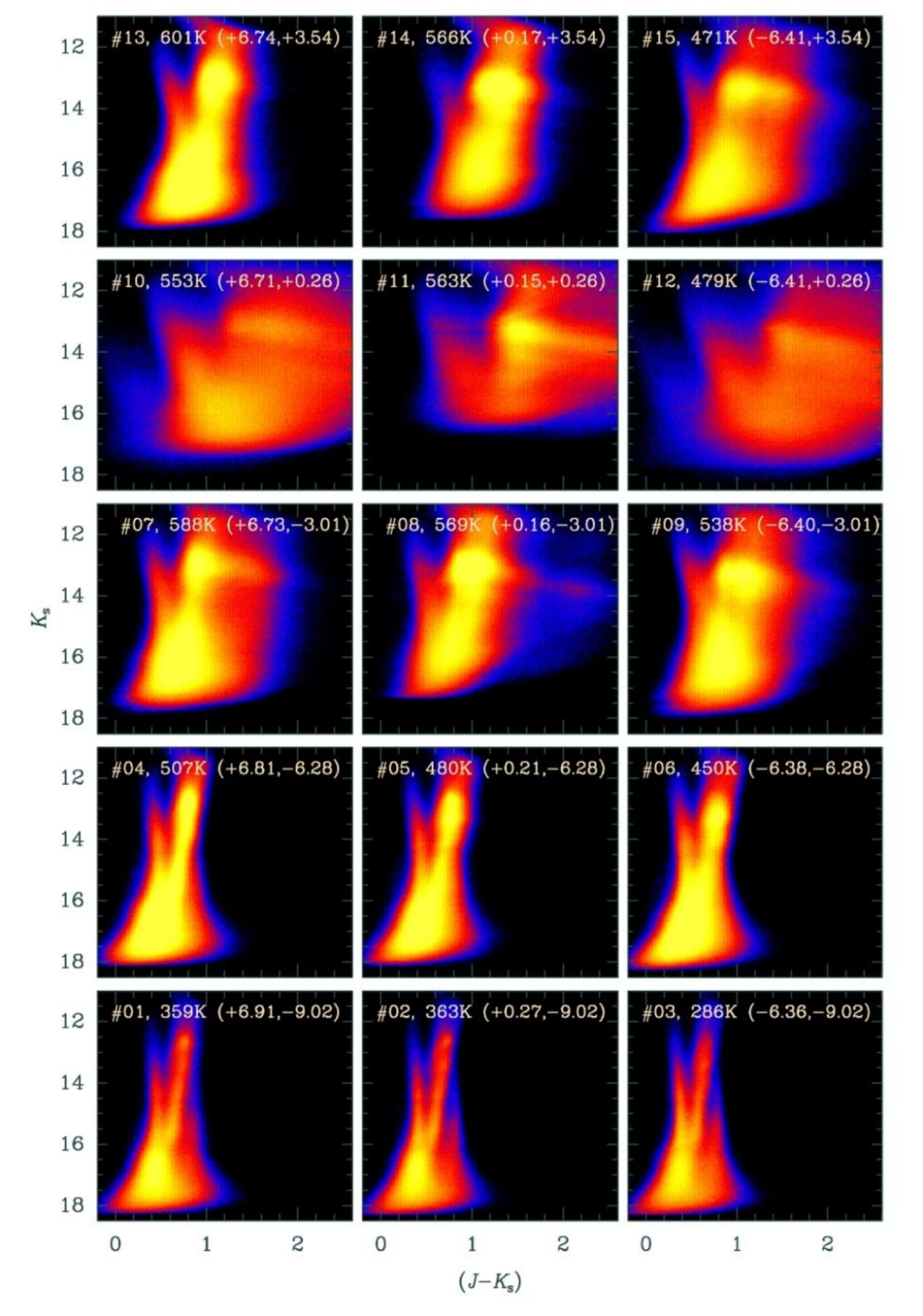
# VVV: 84 million stars (Saito+ 2012)



Saito et al. 2012

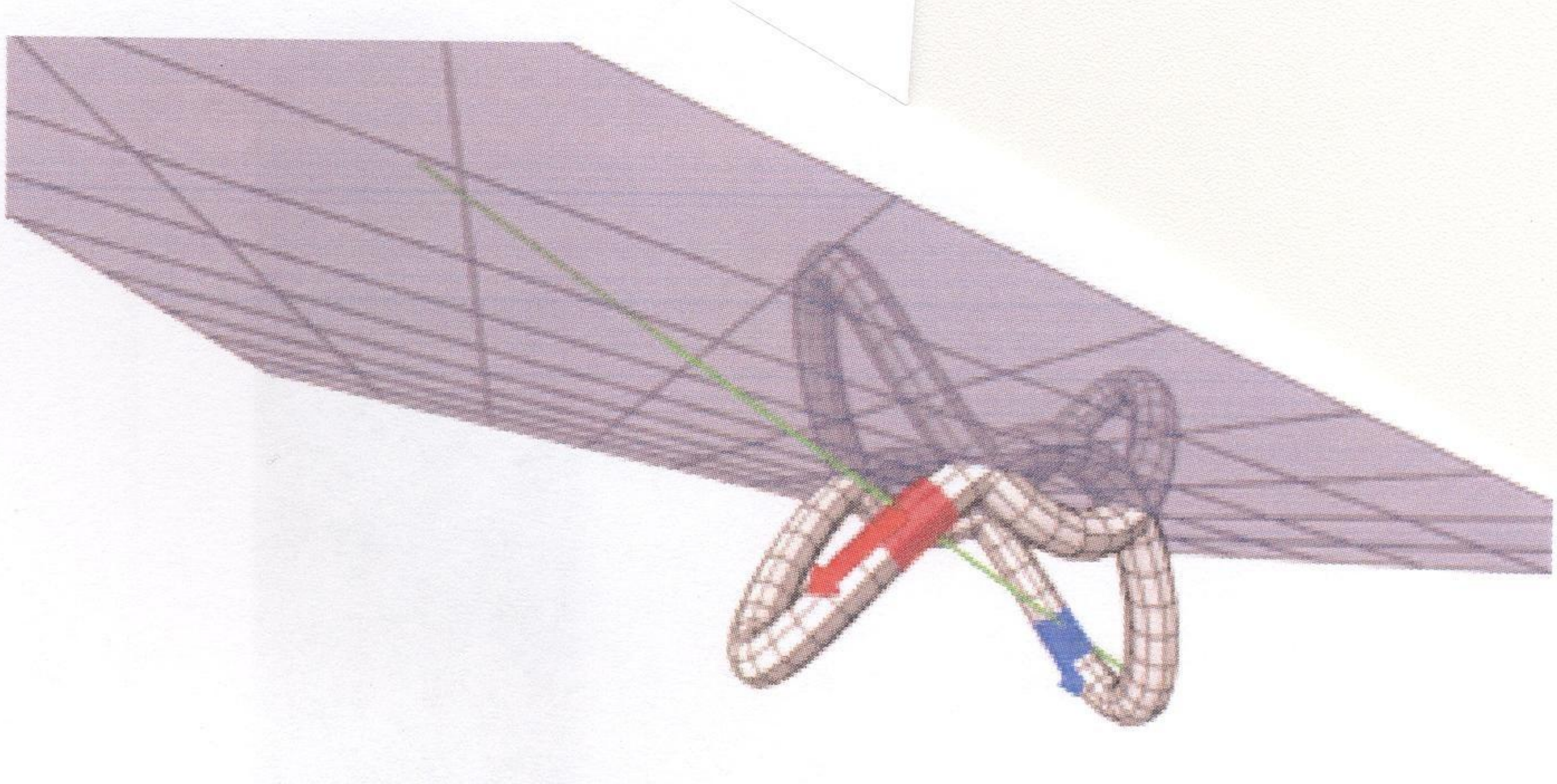
2 red clumps at ‡ distances (~6.5, 8 kpc)

ΔKs clump best seen in #8



# X-shape

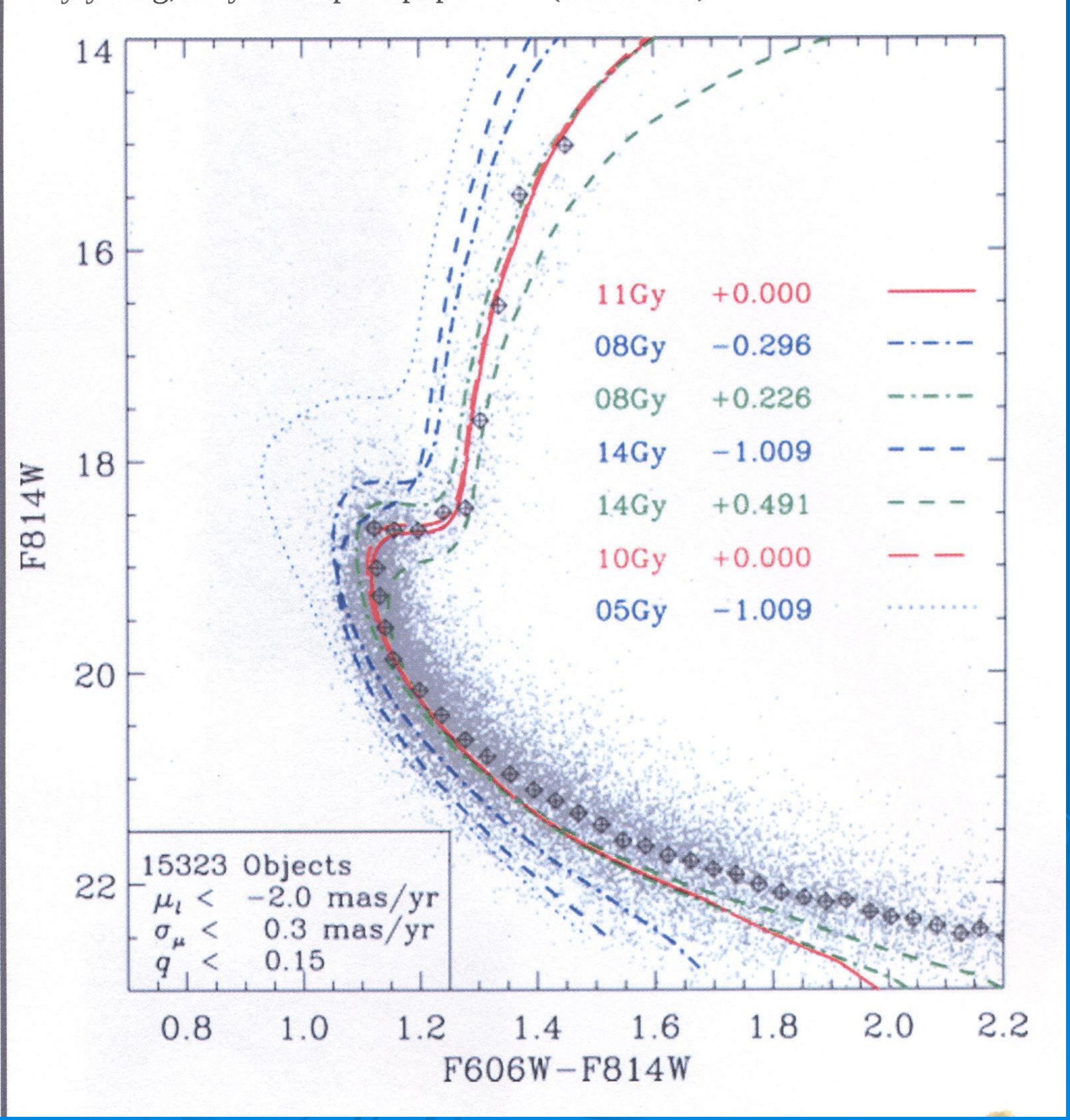
FLAMES: Vazquez, Zoccali et al. 2012



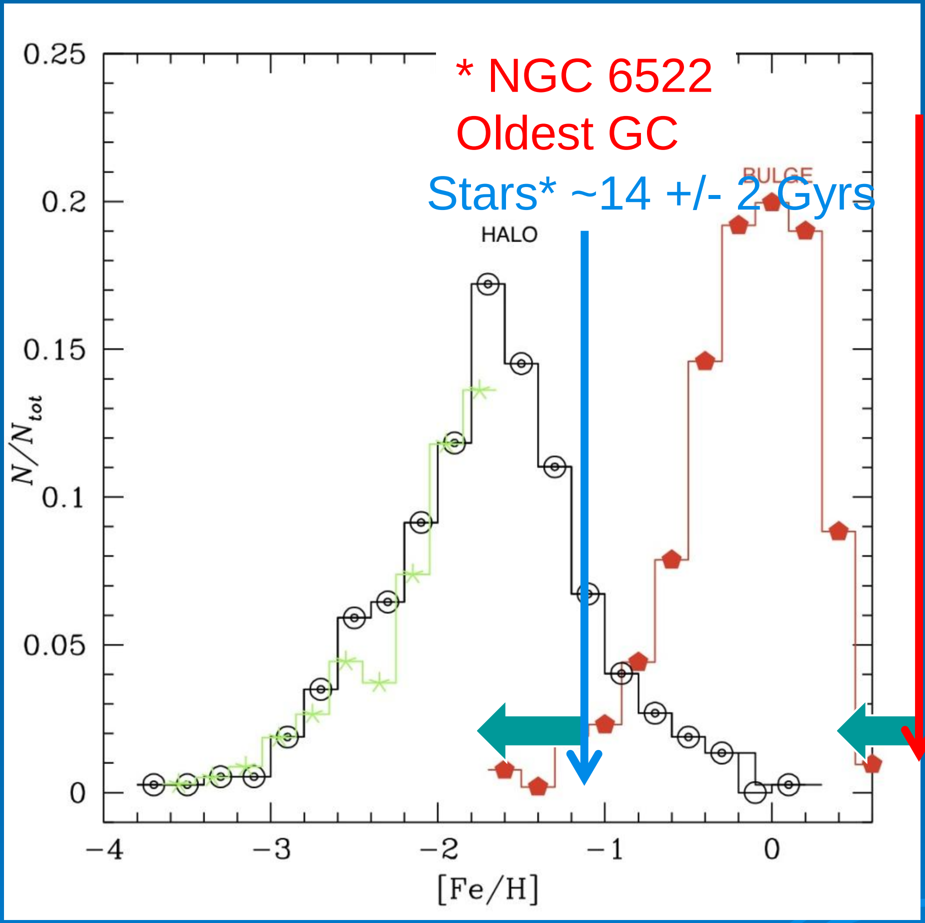
Clarkson+ 2008

Sagittarius Window:
l=1.25
b=-2.65

proper motion cleaned



# Where are the oldest fossil records in the MW?




C.Chiappini, USP Conference 07/02/13

[Fe/H]<-3

[Fe/H]=-1

In the Halo
[Fe/H] < -3

In the Bulge
[Fe/H] ~ -1

Oldest stars are not

Multi-object high-res spectroscopy needed

## FLAMES to observe GIANTS

| | l(°) | b(°) |
|---|---|---|
| BW | 1.14 | -4.2 |
| -6° | 0.2 | -6 |
| -1 | 0 | -12 |
| 6553 | 5.2 | -3 |

**Giants** 1 mag above Horizontal Branch
V~ 15.5 – 16.2

Zoccali+06,08+several papers, ongoing:
55 stars with UVES – R = 45,000
800 stars with Giraffe – R = 22,000

**METALLICITY**

800 bulge field *s

Zoccali+08

**KINEMATICS:**

Babusiaux+10

BW:Metal-rich *s

➔ bar

Metal-poor *s➔

spheroid or thick

disk

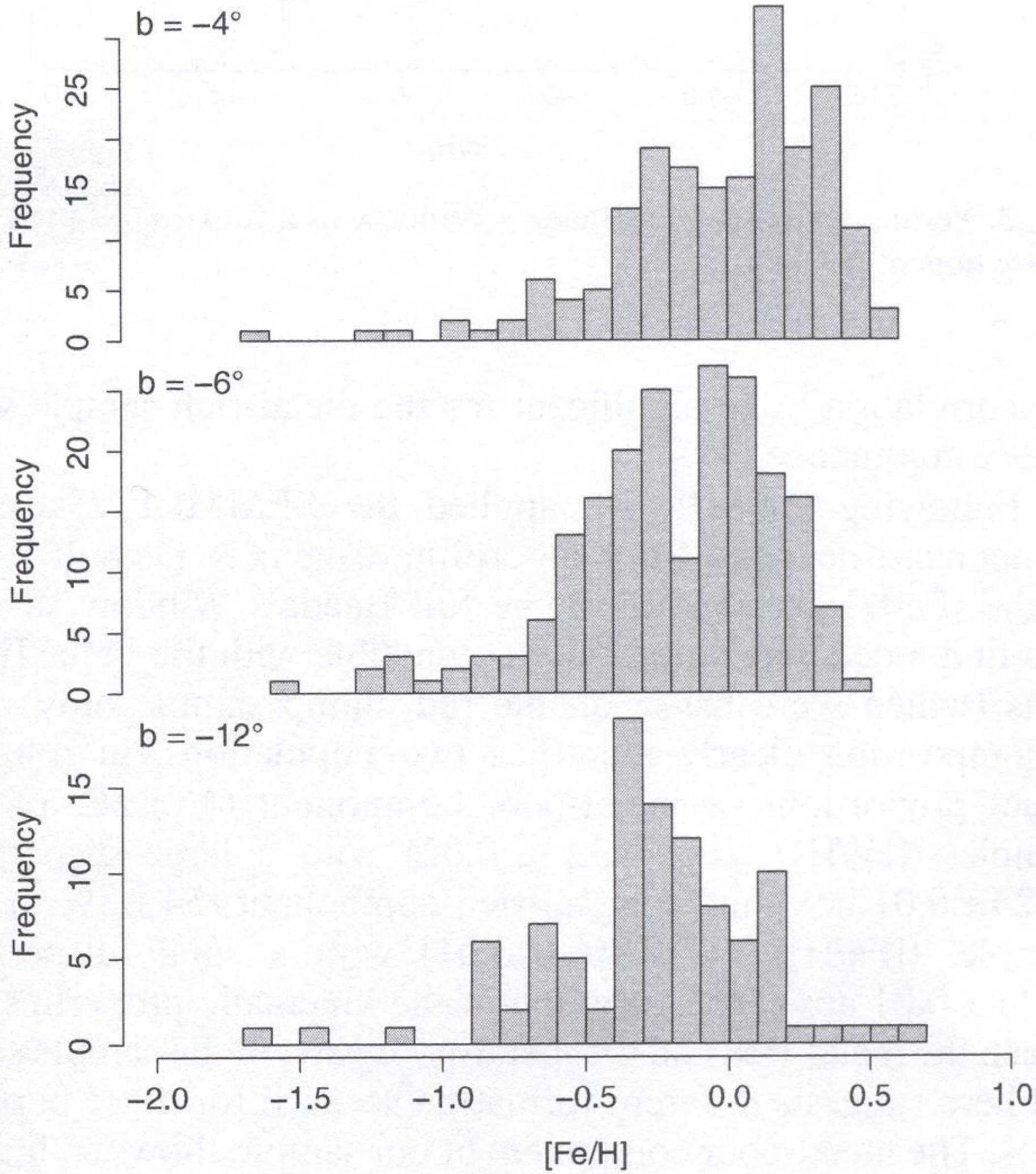



**Fig. 5.** Distribution of the metallicity for the different galactic latitudes of Paper I.

# Gonzalez et al. 2011

GIRAFFE
spectra
650 stars

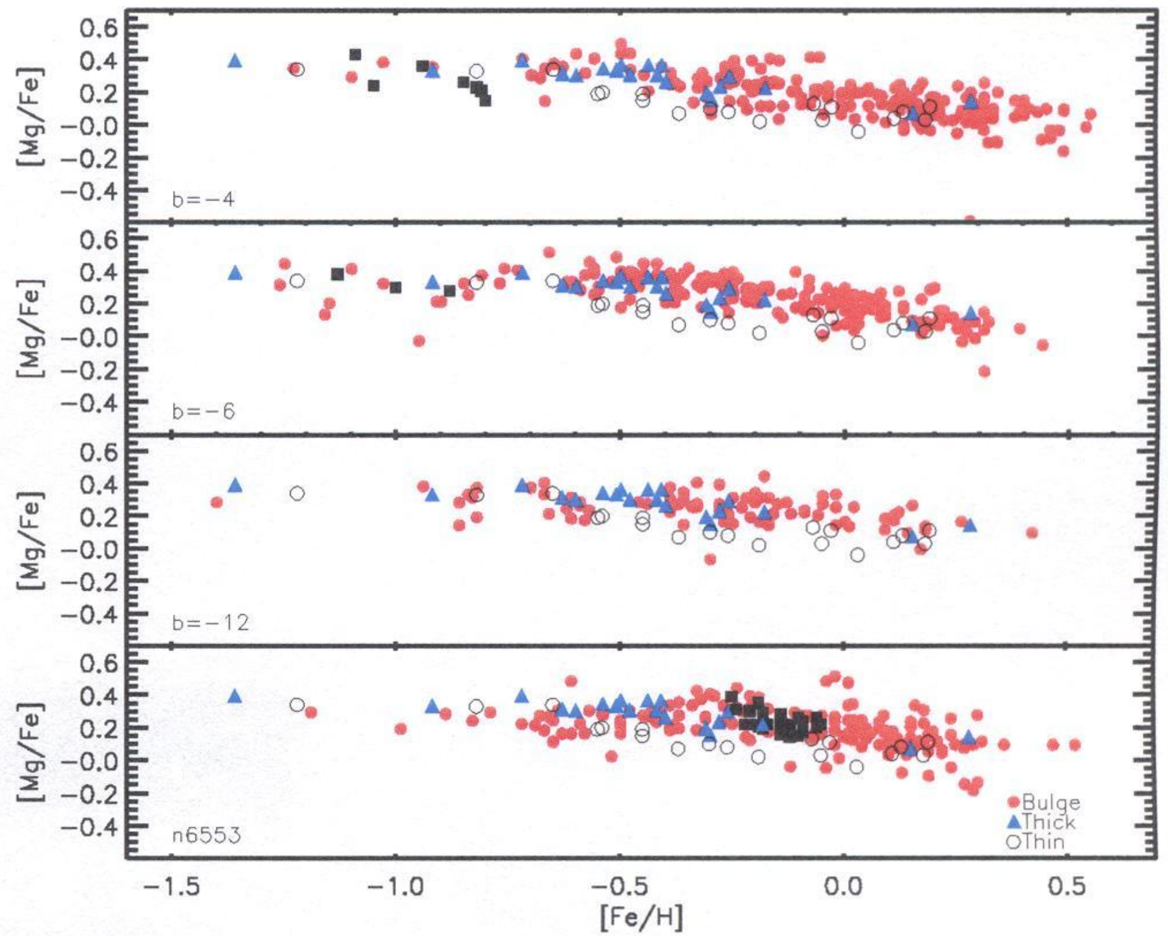
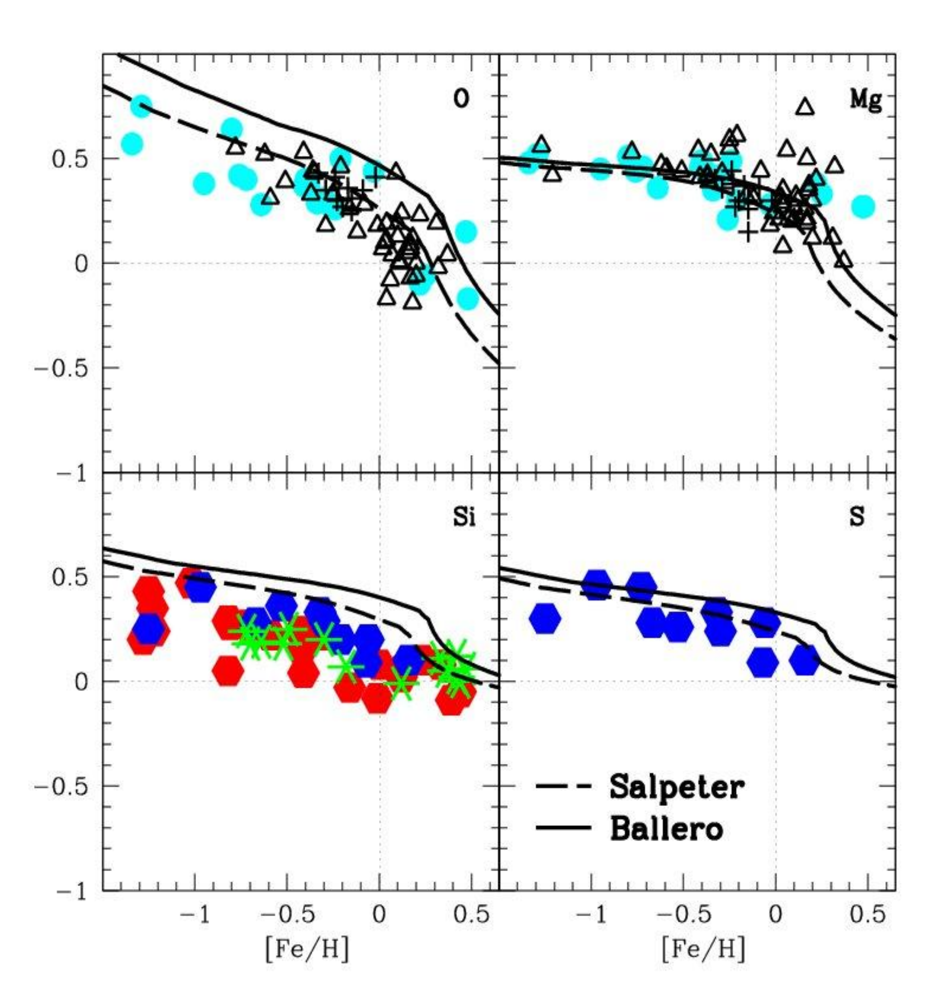



**Fig. 10.** [Mg/Fe] abundances in 4 fields of the bulge shown as red filled circles. Bulge globular cluster members are shown as black filled squares. [Mg/Fe] abundances for the thick disk stars are shown as blue filled triangles and as empty black circles for the thin disk stars.

# Cescutti & Matteucci 2011,A&A,525,126

- Intense 10xSFR and short timescale of formation, 0.1-0.3Gyr
- O and Mg: (Zoccali+06; Fulbright+06; Lecureur+07)
- Si,S (Alves-Brito+10;Ryde+09 ;Bensby+10)



# CONCLUSIONS ON BULGE FIELD

If X-shape is an indication of a pseudobulge, there remains to explain:

- Kinematic difference between metal-poor and metal-rich stars
- alpha-element enhancement

- F. Combes: the bar can form later involving the old stellar populations. The bar shape is not a proof of origin of bulge, the stellar populations instead are a proof.

## Formation of inner bulge metal-poor Globular Clusters:

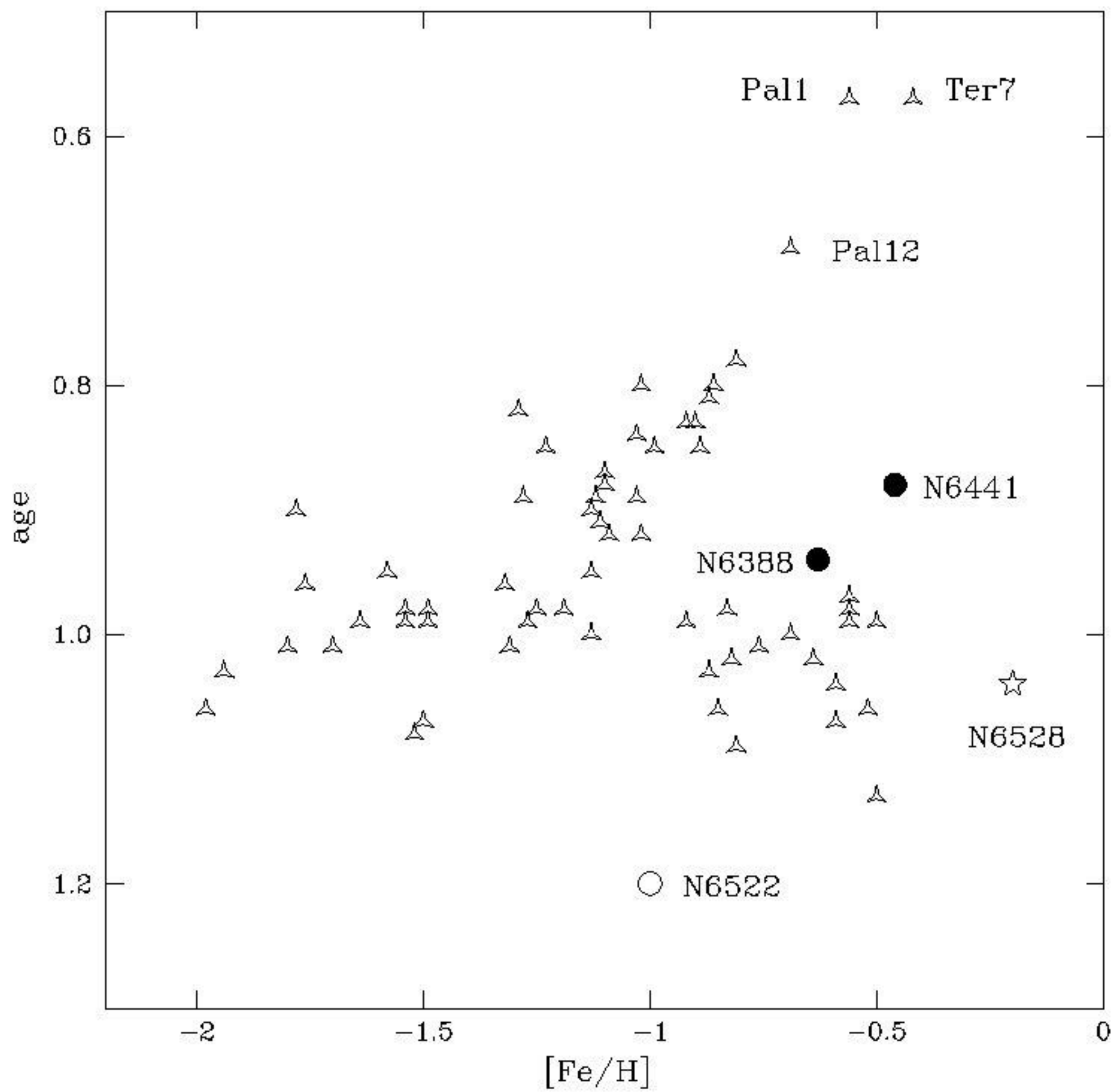
First generation of massive fast-evolving stars: high redshifts (Gao et al. 2010).

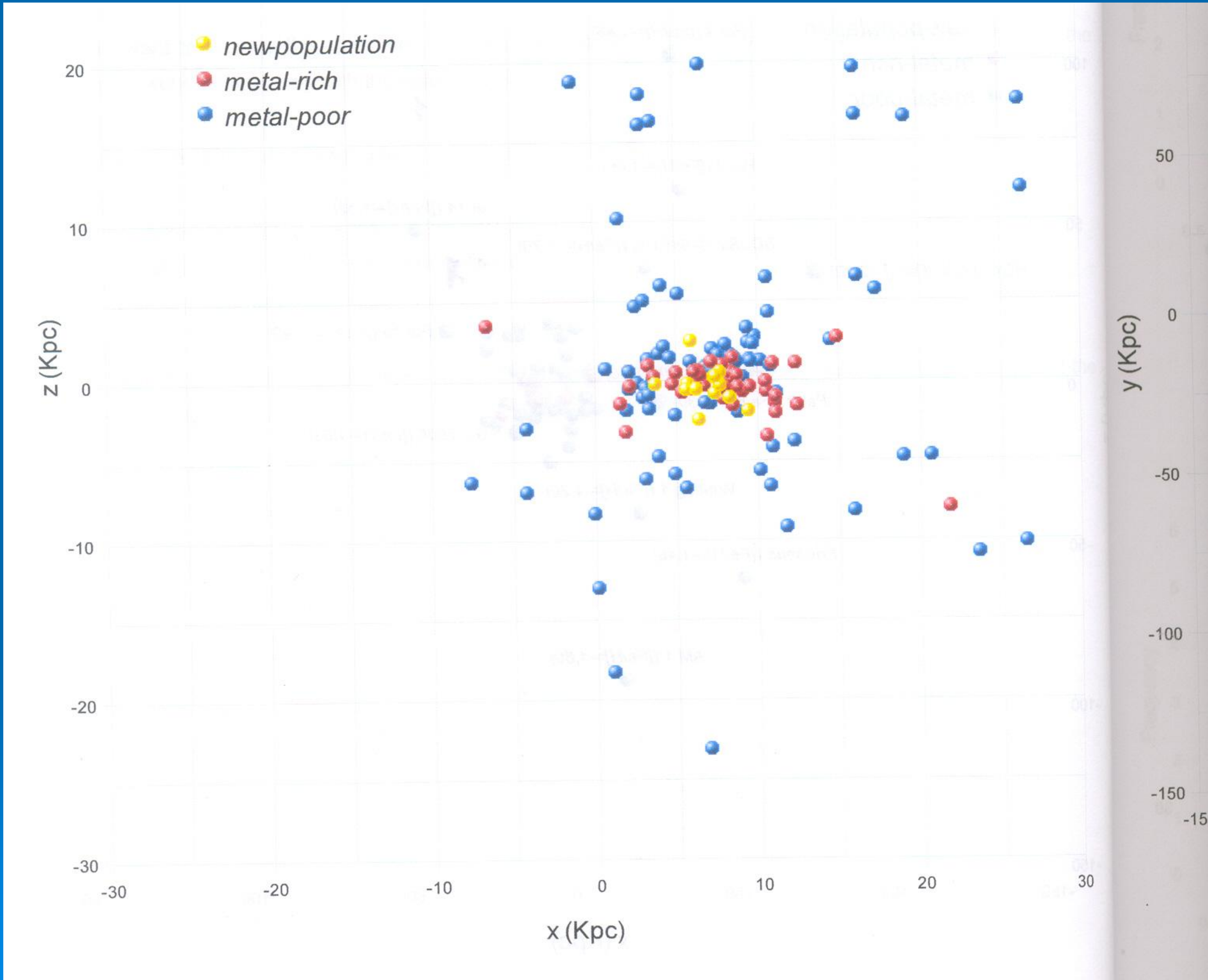
Second generation of low-mass stars: forming in inner parts of galaxies.

# Metal-poor globular clusters in the Galactic Bulge

Marin-Franch+09

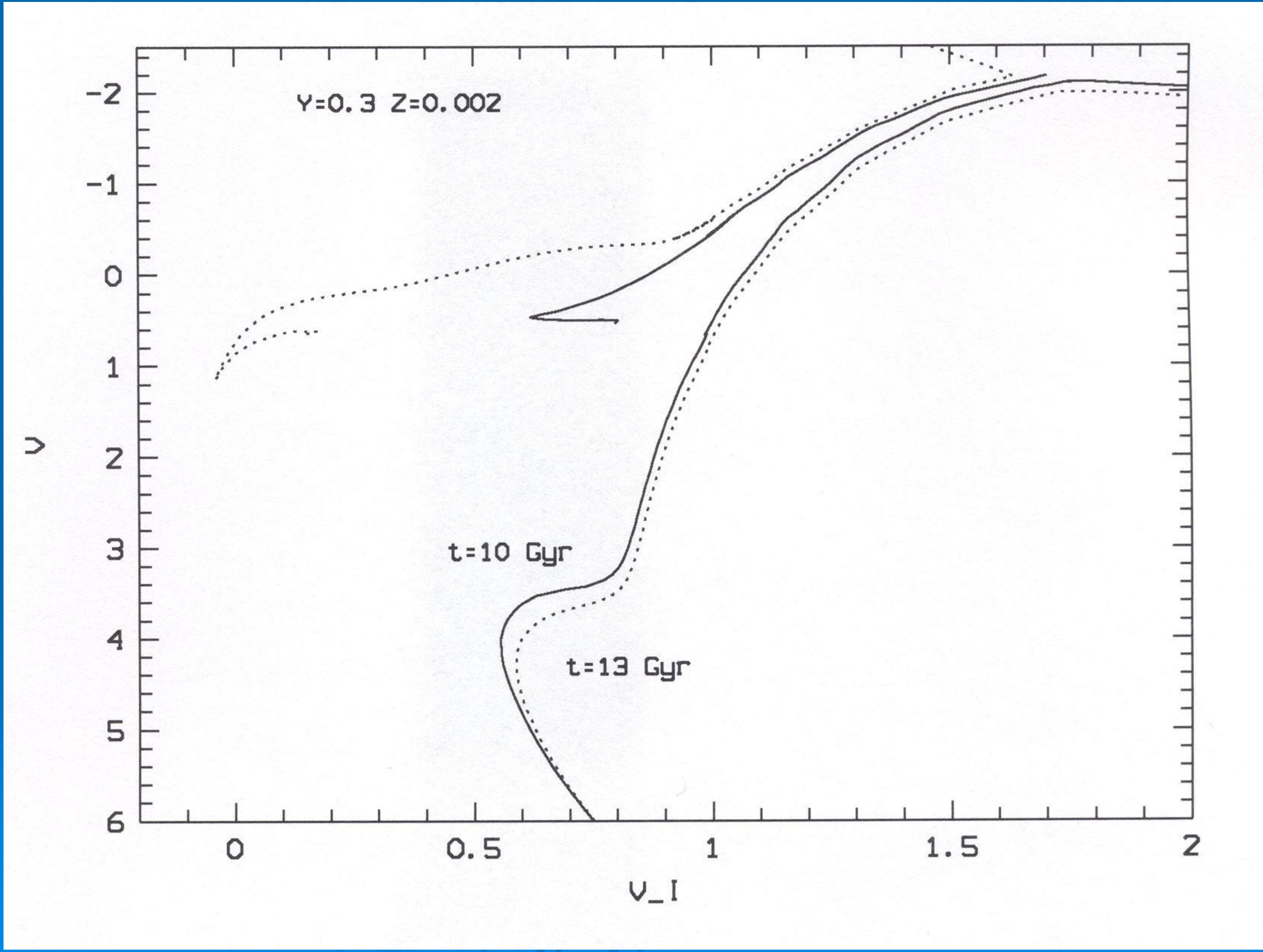
added: NGC 6522: oldest so far




new-population
metal-rich
metal-poor
20
10
z (Kpc)
0
-10
-20
-30
-30
-20
-10
0
10
20
30
x (Kpc)
50
0
-50
-100
-150
-150
y (Kpc)

# Metal-poor GCs:
# Padova, Y=0.30, ages = 10, 13 Gyr

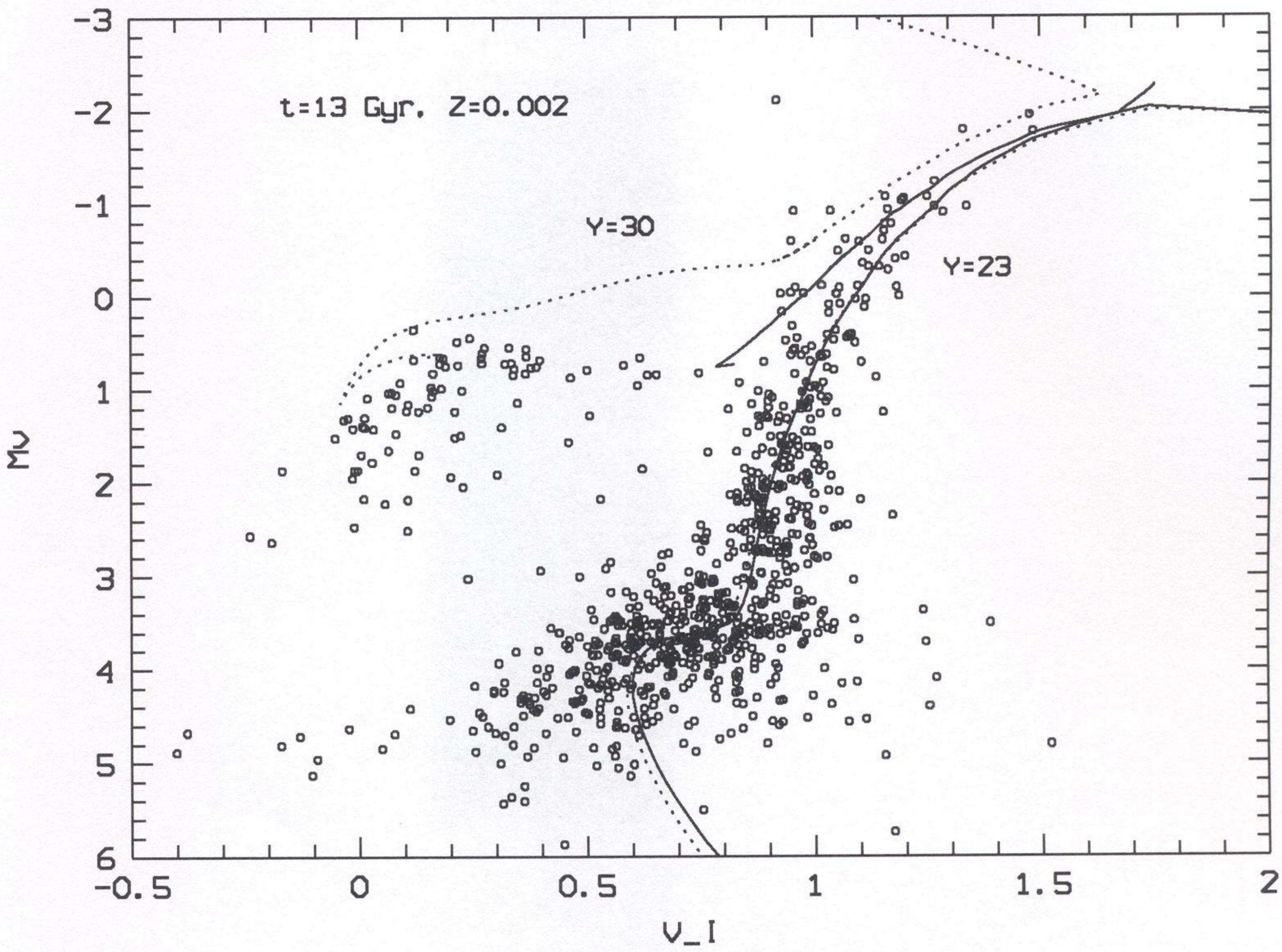
BHB:
Old



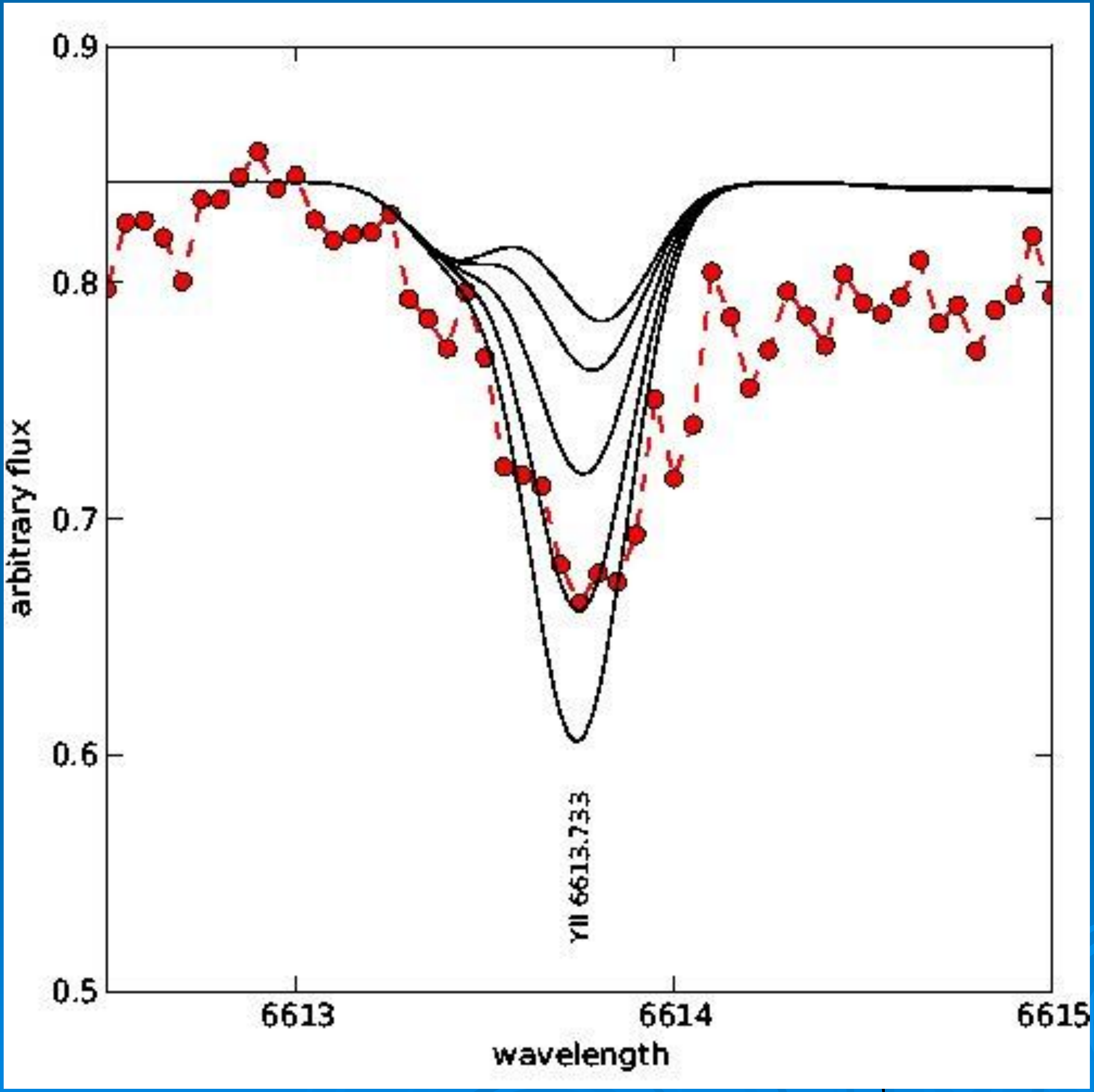
# Padova 13 Gyr Z=0.002, Y=0.23, 0.30

or

He-Rich?



# Evidence of enrichment by Massive spinstars




Chiappini+ 2011 Nature 472, 454

Excess Y confirms

## CONCLUSIONS ON METAL-POOR GCs:

Oldest objects in the Galaxy?

Younger if He-enhanced: counts on blue extended HB needed

Metal-rich inner bulge GC NGC 6553: RGBB/RC~0.3 – He not enhanced

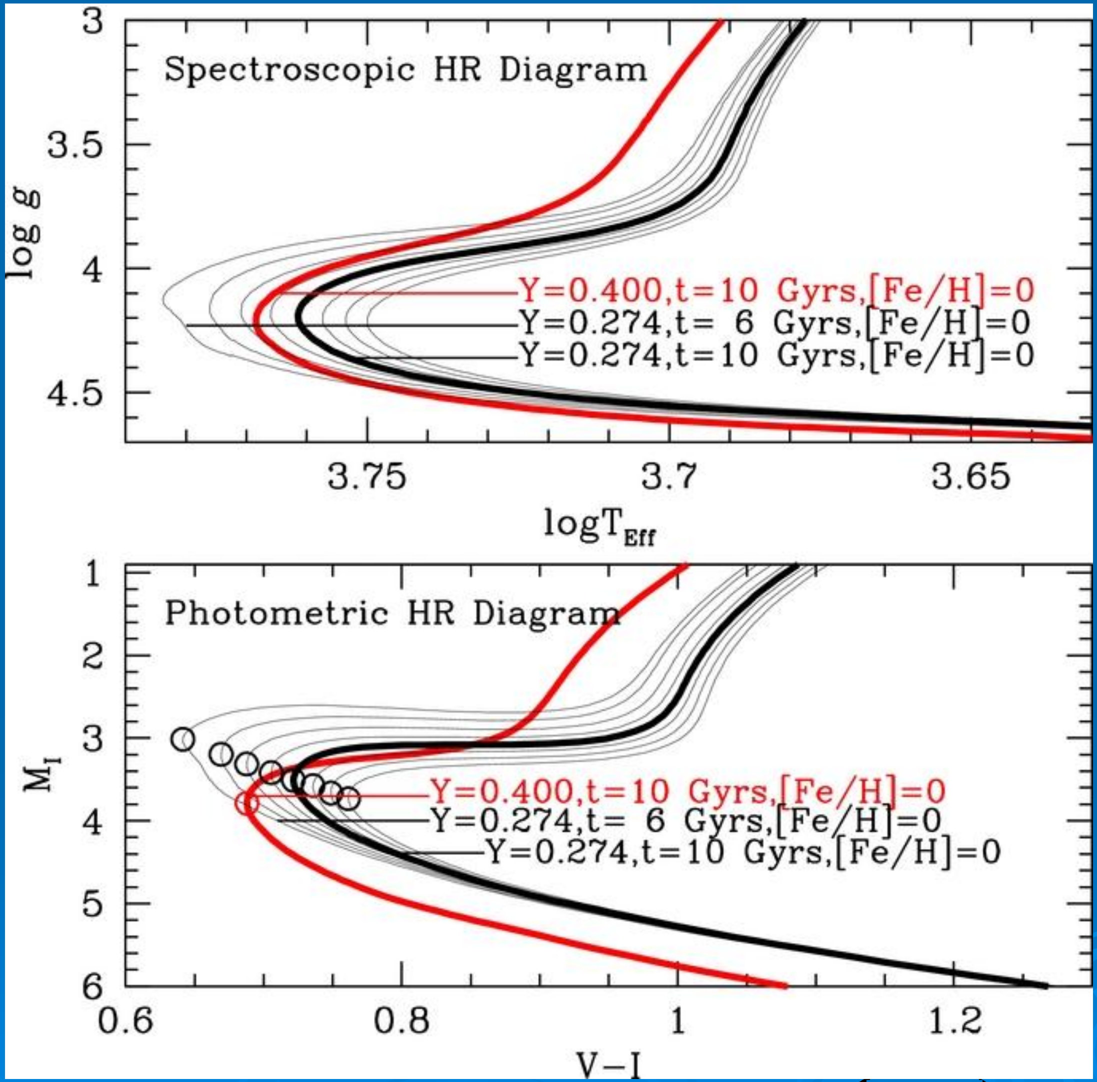
Field and GCs: further evidence on enrichment by fast rotating massive *s: Ba, Y, He

# SCIENCE ONLY FEASIBLE WITH MULTI-OBJECT HIGH-RES IN >8m CLASS

E-ELT → SGB and Turn-off stars

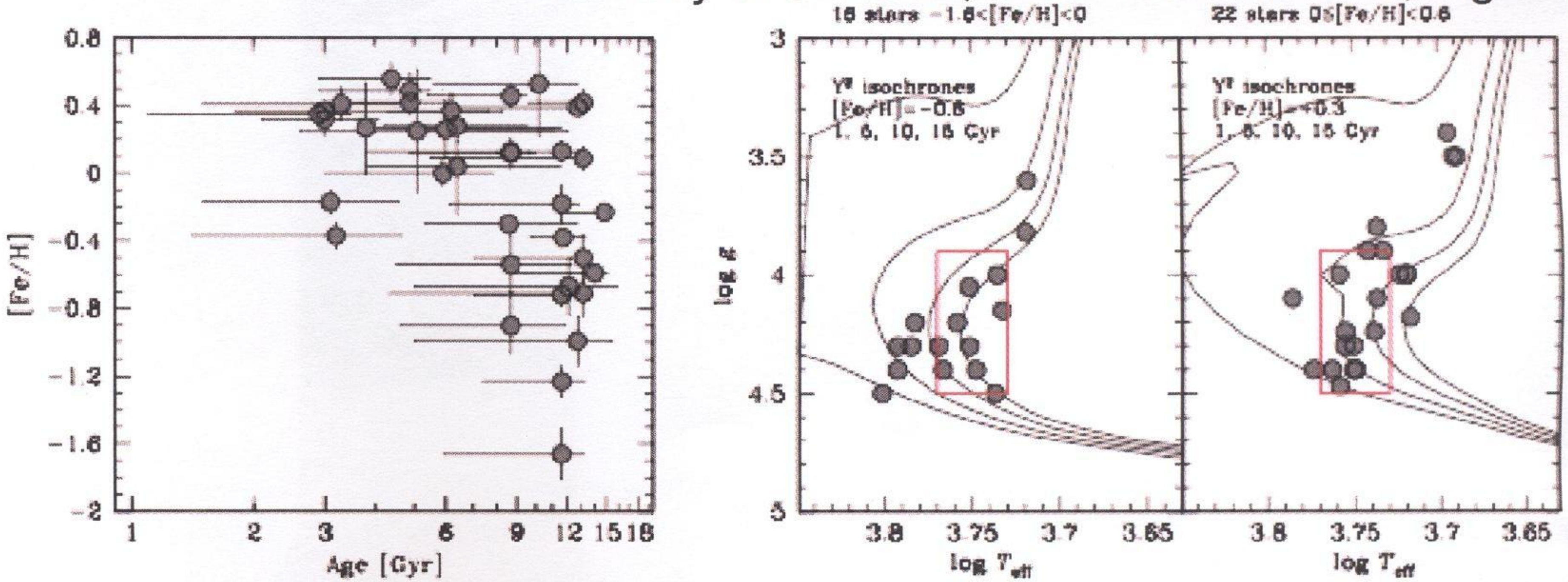
Done so far in 38 microlensed such stars

# Microlensed dwarfs: high He



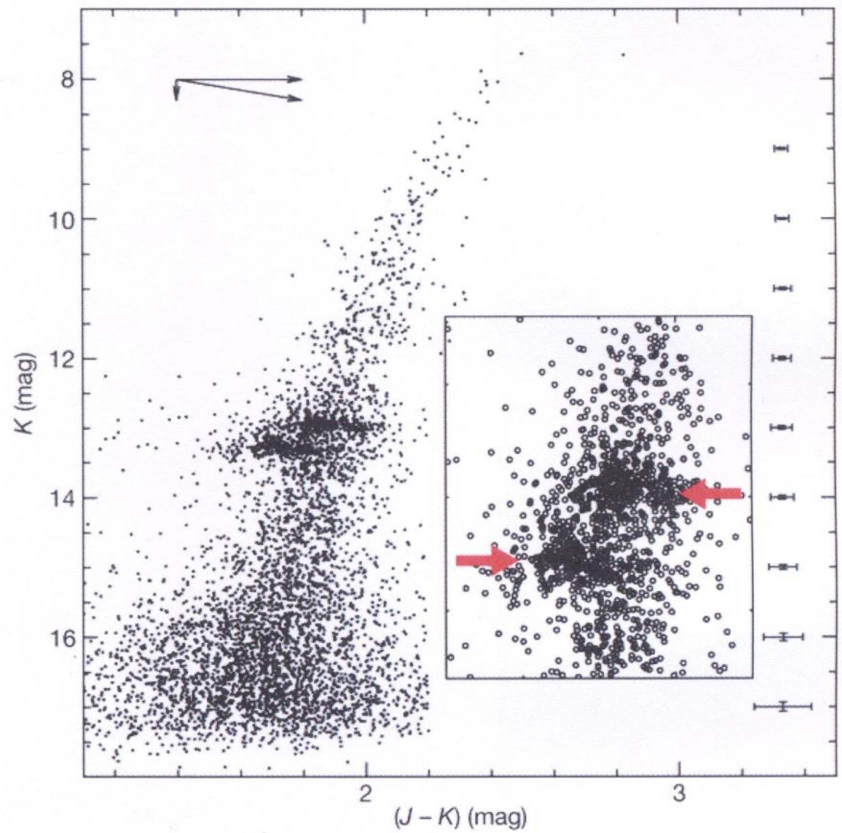
- Bensby et al. (2011, 2012) find evidence for an intermediate ag population in a sample of 38 microlensed dwarfs, 16 (40%) are younger than 7 Gyr

Bensby et al. 2012, arXiv:1201.2013v1, Fig. 1



Multiple Pops

The two horizontal branch clumps of Terzan 5.




FR Ferraro *et al.* *Nature* **462**, 483-486 (2009) doi:10.1038/nature08581

nature

# From VLT science to E-ELT science:

•Giants observed in the last 10 years and continuing in the next 10 years

FLAMES+UVES: one field with 7 UVES stars at V~16.5 ➔ 7h to 1 full night

Together with deep CMDs and proper motion cleaning, we will be prepared to study dwarfs

➔ We need to understand better giants and dwarfs together

➔SGB and Turn-off stars of bulge field/clusters:

-Model atmosphere more reliable, since closer to the Sun; in particular 3D models
-non-LTE approximations are better fulfilled
-Gravity values better defined

-Ages from precise log gxTeff
-Unmixed element abundance pattern
-He from CMDs plus spectroscopy

➔And clearly: multiple populations in the Galactic bulge field, to be disentangled

# Need for E-ELT:

Turn-off magnitudes:

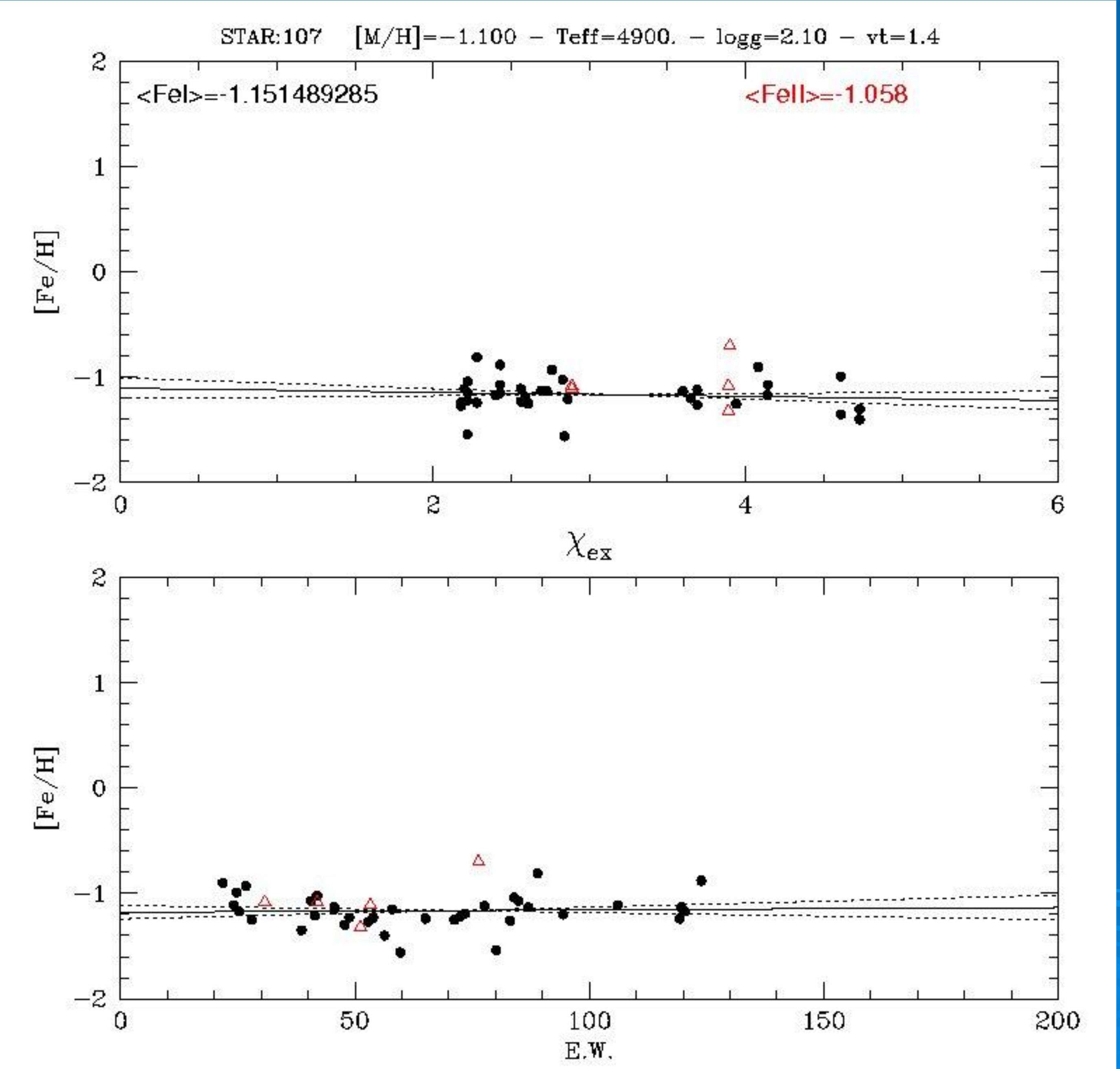
Baade's Window: V(TO) = 19.5,H(TO)~18
NGC 6528: V(TO) = 20.8, H(TO)~18.5
NGC 6522: V(TO) = 20.4,H(TO)~18

➔UVES limit: V~<17
GIRAFFE: V~<18
➔Very difficult with 8m even in IR
(never done except with microlensing)

# Need for optical spectra:

1) FeI, FeII lines of varied $\chi_{ex}$
in IR most lines of FeI with
$4.5 < \chi ex < 6.5$

Optical is far more suitable for derivation of spectroscopic effective temperatures


STAR:107 [M/H]=−1.100 − Teff=4900. − logg=2.10 − vt=1.4
<FeI>=-1.151489285
<FeII>=-1.058
[Fe/H]
2
1
0
−1
−2
0
2
4
6
$\chi_{ex}$
[Fe/H]
2
1
0
−1
−2
0
50
100
150
200
E.W.

2) Oxygen OI 777nm, [OI] 630nm
Only cool stars will show IR OH lines

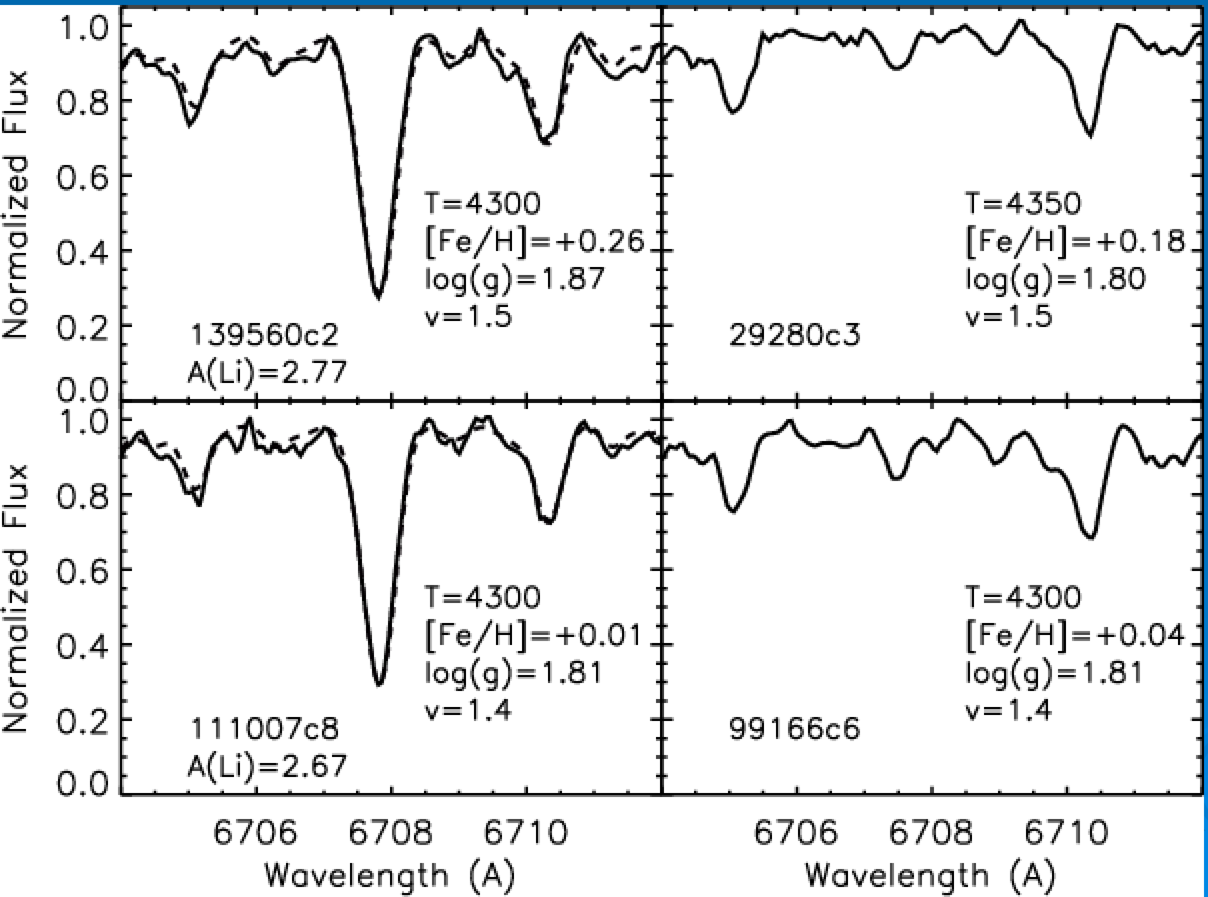
3) Many lines of heavy-elements: Ba, Y, Nd, Ce, Sr, Zr

4) Many lines of alpha-elements:
Mg, Si, Ca, Ti – a few possible in IR

Note: C,N possible in IR and optical

# 5) Lithium LiI 670.7 nm

To be measured in SGB and dwarf turn-off stars (Li is destroyed in cool giants).



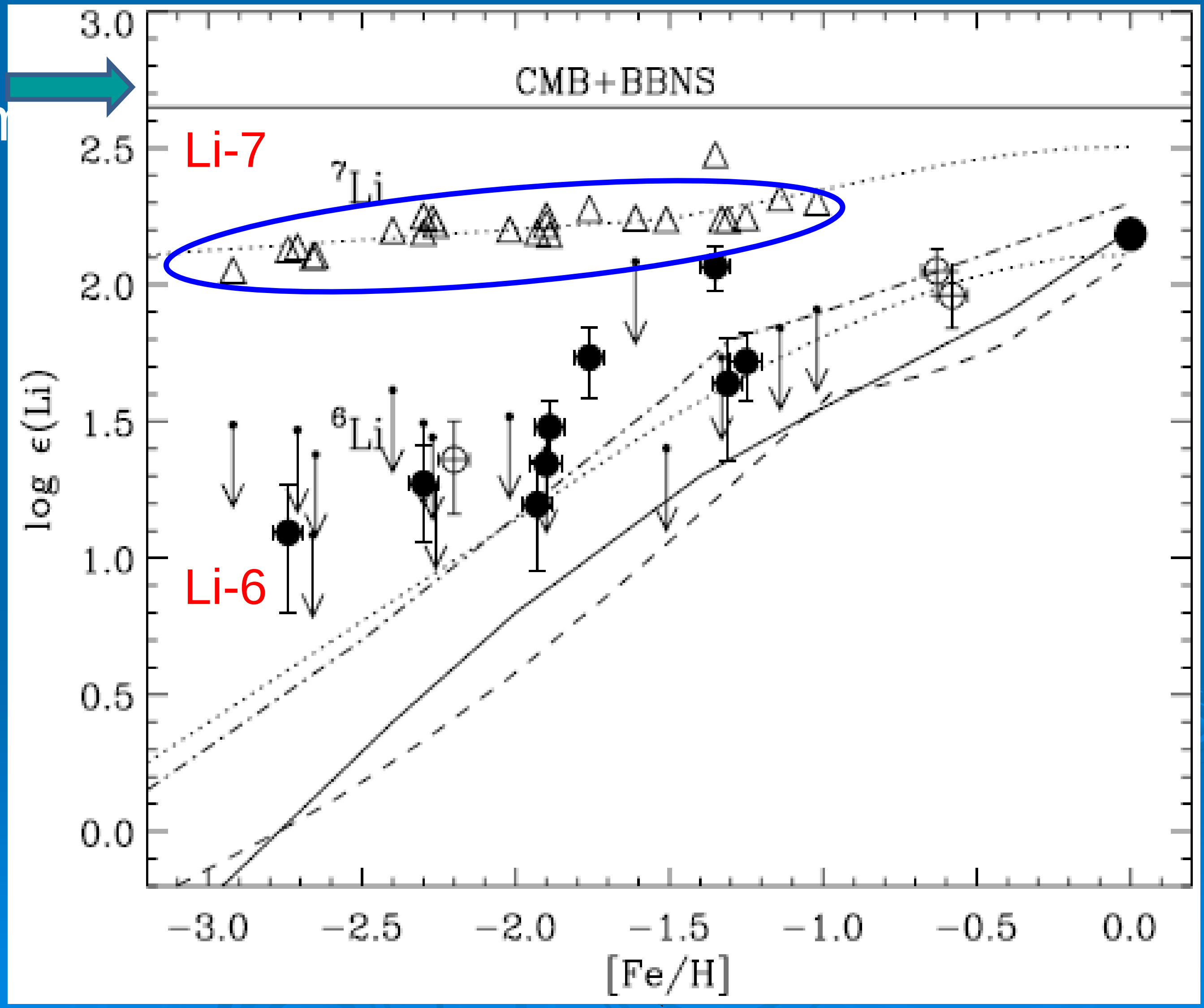

Gonzalez+09

Li in giants
~1% of sample

# Cosmological lithium problem

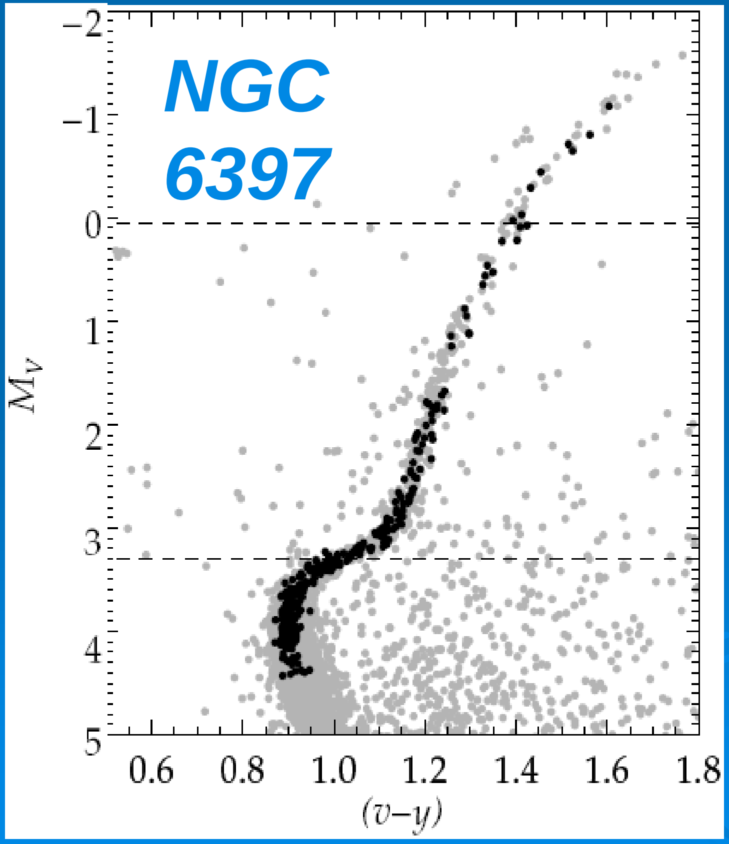
BBN+WMAP
Primordial lithium

BBN prediction is about a factor of 4-5 higher than Li in field halo stars



# Evidences of Li depletion using globular cluster stars

Korn et al. 2006, Nature 442, 657



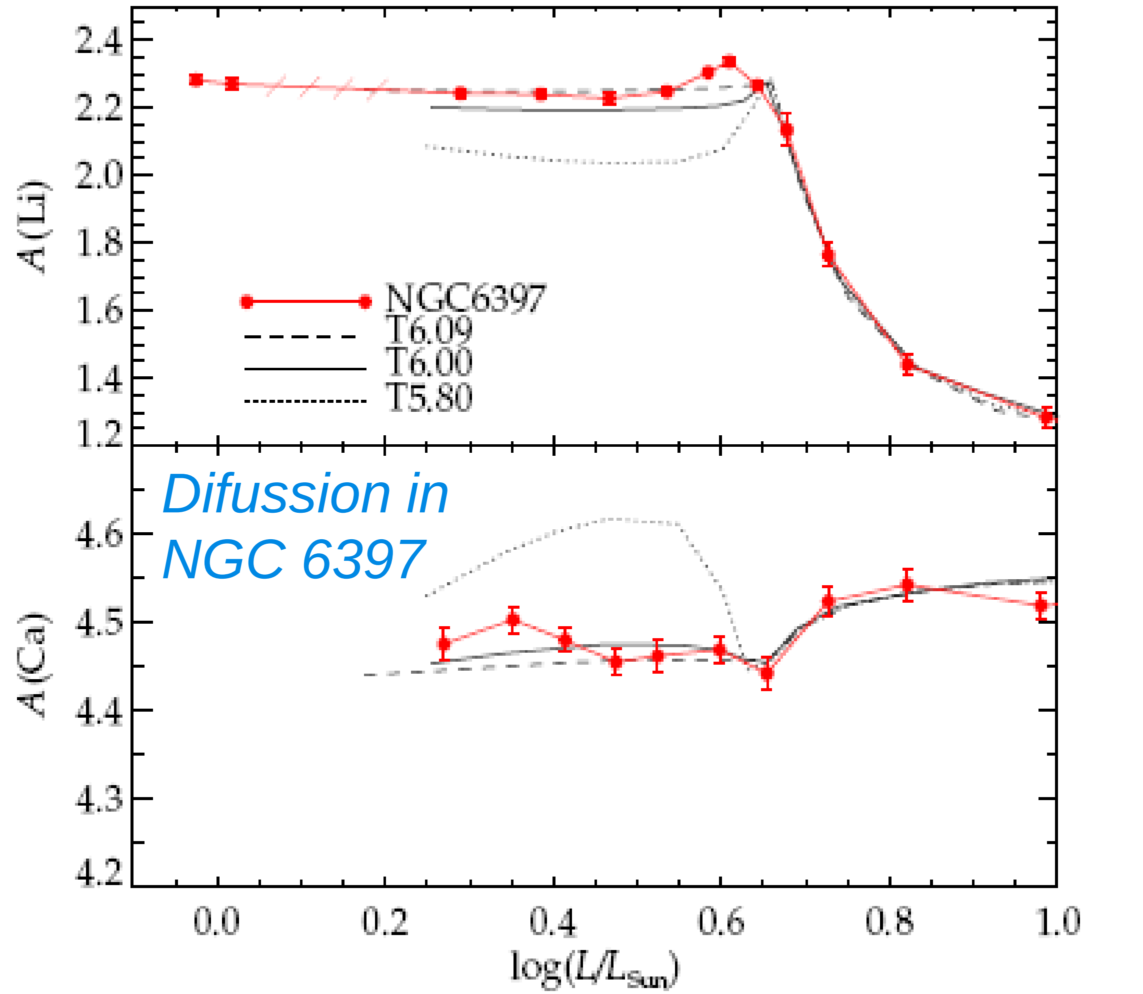
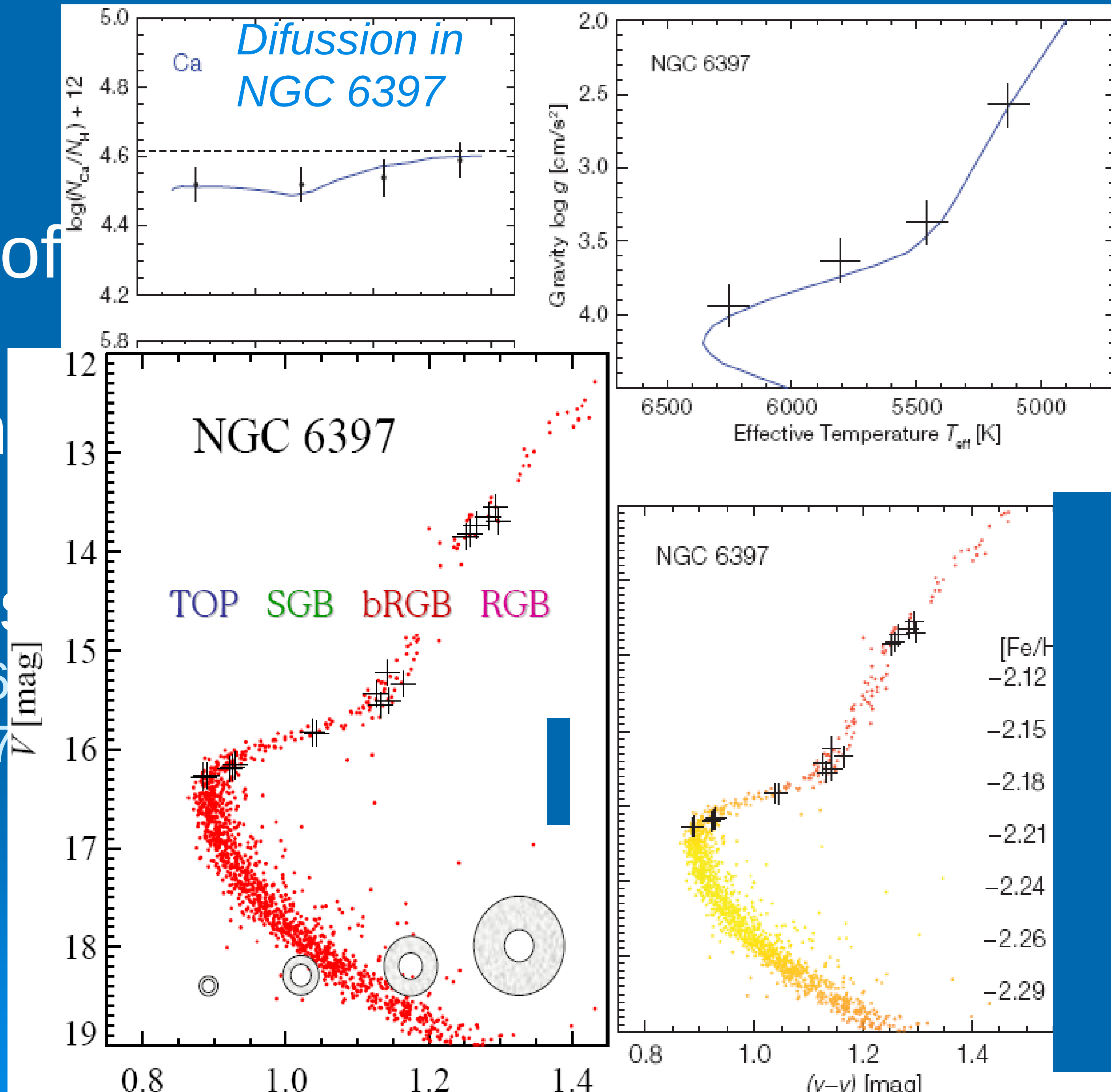




**Fig. 10.** *Top:* Comparison between bin-averaged Li abundances (red filled circles connected with solid lines) and the predictions from the stellar-structure models of Richard et al. (2005). T5.80 represents the model with lowest efficiency of turbulent transport, T6.00 intermediate efficiency, and T6.09 highest efficiency. The reference scale is logarithmic luminosities in units of solar luminosities. *Bottom:* The same plot for Ca abundances. A

# Evidences of atomic difussion in globular cluster stars

Korn et al. 2006
Nature 442, 657



# ELT+MOSAIC+link to HIRES

We aim at faint objects, with multiplex.
Better data quality:  higher S/N.
In some cases also higher R, to achieve better understanding of stellar physics

| ELT, V=20 | ELT, V=20: |
|---|---|
| MOSAIC+HIRES | MOSAIC+HIRES |
| R = 47 000 | R = 100 000 |
| S/N = 100 | S/N = 100 |
| Only 10-14 hours! | Only 2 nights! |

The End