Metallicity distribution and kinematics in the Carina dSph

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ESO - RASPUTIN
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Why Dwarf Spher. Galaxies?

dSph galaxies are small and relaxed stellar systems

Low stellar mass	~ 10^7 $M_\odot$
Low internal velocity disp.	~ 10 km/s
High M/L	> 10 $M_\odot/L_\odot$

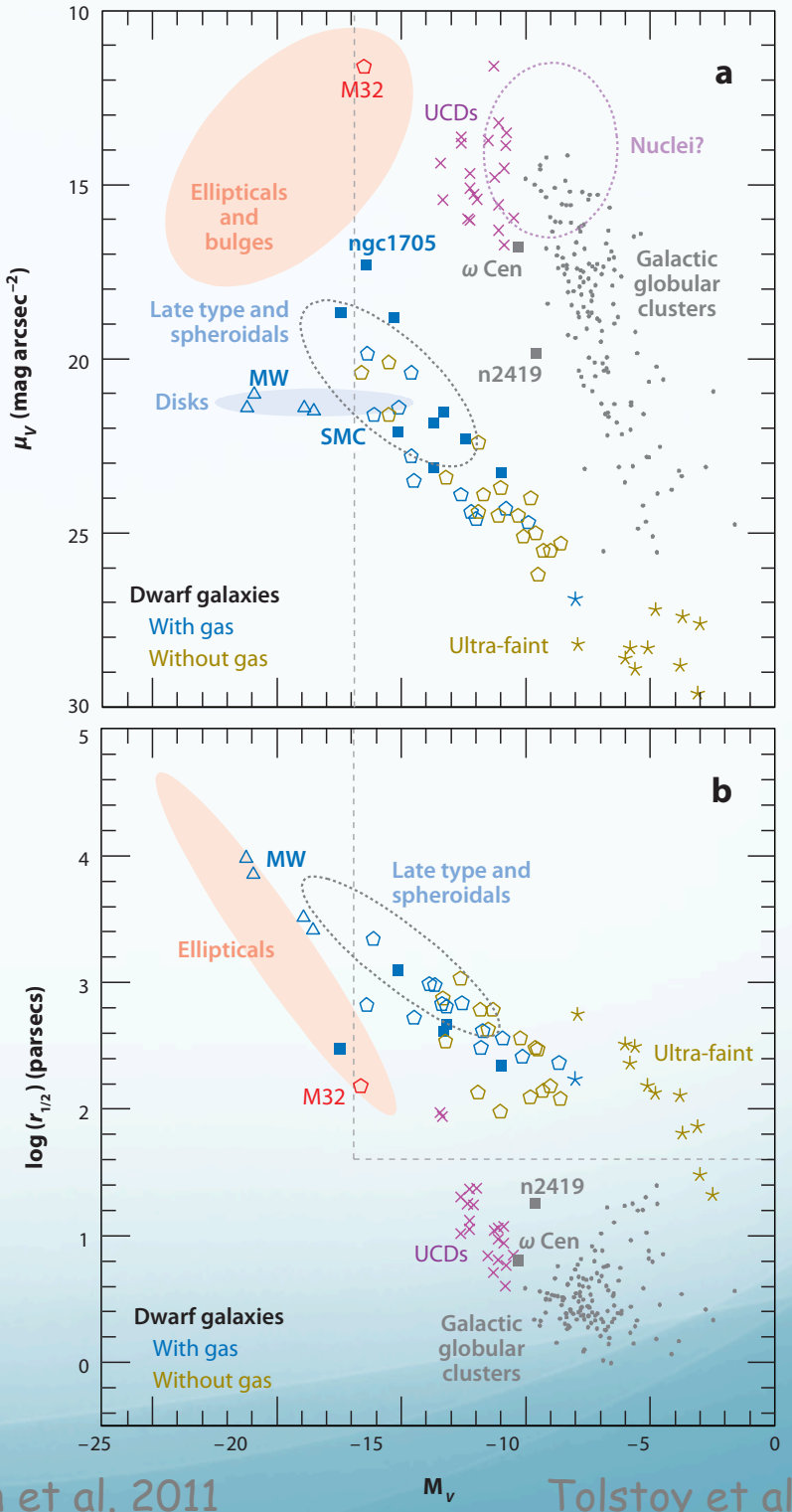
They could be the building blocks in the galaxy formation theory

There is not a clear transition between Sphs and Es

Suggestions for galaxy formation scenario:

-Ellipticals form via mergers

-Spheroidals are defunct irregulars



Mateo 98; Kormendy et al. 09; Graham et al. 11, Chilingarian et al. 2011

Tolstoy et al. 09

Why Carina dSph?

Close ~100kpc

Low density $\rho = 0.17\ M_{\odot}/pc^3$

Well separated radial velocity peak from field stars

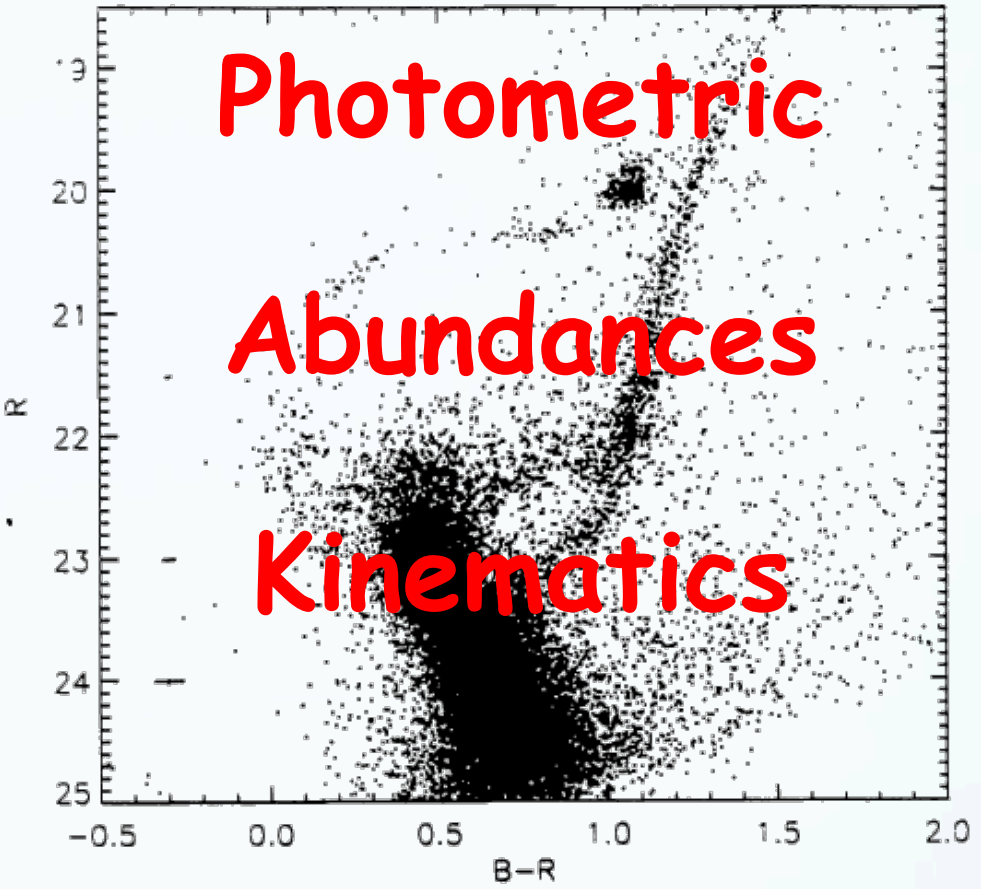
Multiple separated star formation episodes

Metallicity distribution from ~-2.5 to ~0.5 dex

Photometric

Abundances

Kinematics



Parameter	Values
α (J2000)	06 41 37
δ (J2000)	−50 58 00
M_V[a] (mag)	−8.9
r_c[b] (arcmin)	$11.96 \pm 1.5/14$[c]
r_t[d] (arcmin)	$22.54 \pm 1.4/32$[e]
e[e]	0.32 ± 0.04
P.A.[f] (deg)	64 ± 2.5
σ_p[g] (km s^{-1})	6.8 ± 1.6
[Fe/H][h]	-2.0 ± 0.30
$E(B-V)$[i]	0.04 ± 0.02
$(m-M)_0$[j] (mag)	20.03 ± 0.09

Smecker-Hane et al. 1996
Mateo 1998
Monelli et al. 2003

Carina project data

Spectroscopic

UVES@**VLT 8m**

(R~40,000 - Slit&Fibers) 95h

GIRAFFE HR (R~20,000 – Fibers) 24h

GIRAFFE MR (R~6,000 - Fibers) 95h

FORS2 (R~2,000 - Slits) 19h

VIMOS (R~600 – Slits) 25h

~22,340 individual spectra

~2,700 stars covering the entire body of galaxy

Complete coverage until tidal radius + external pointing ~1°

Photometric

Tektronix2K@**CTIO 1.5m**

WFI@**ESO/MPG 2.2m**

MosaicII@**CTIO 4m**

HAWK-I@**VLT 8m**

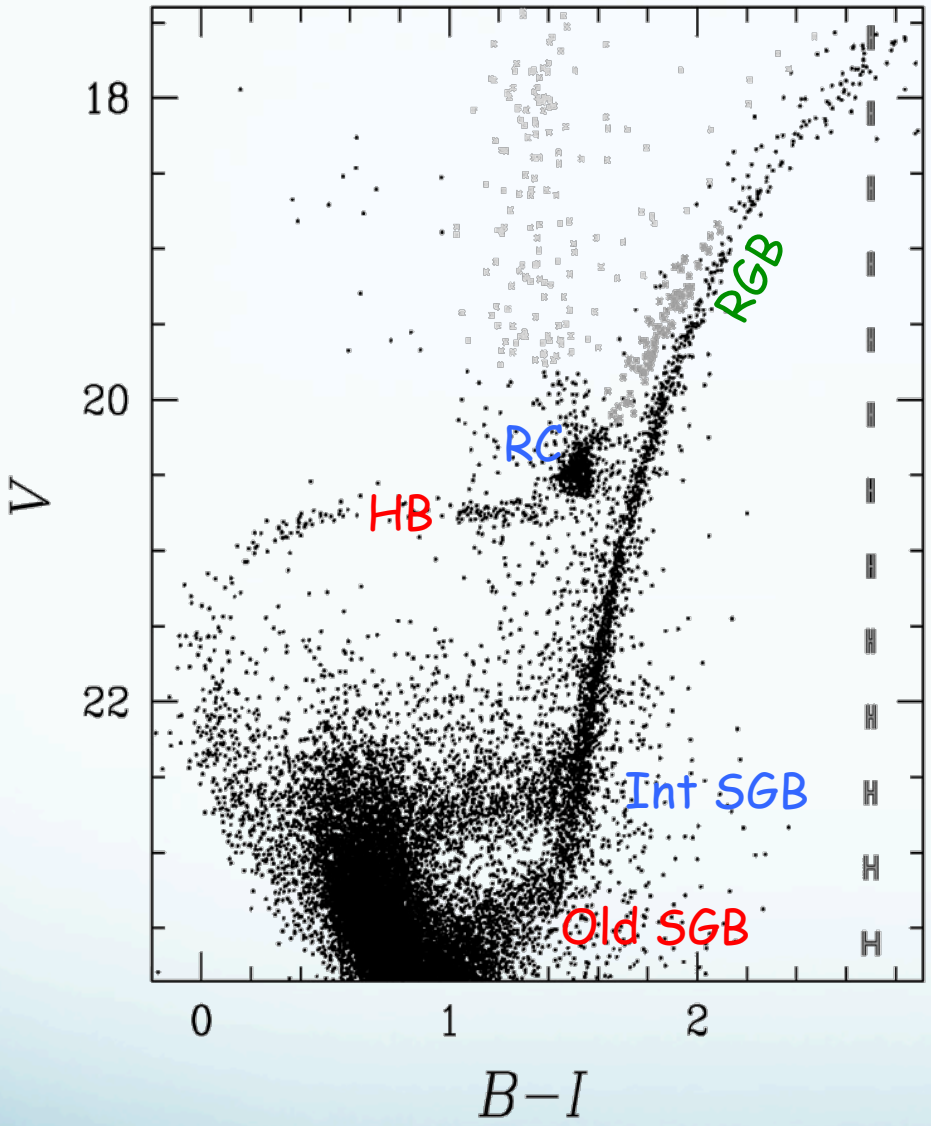
4,152 individual CCD images

~120,000 stars

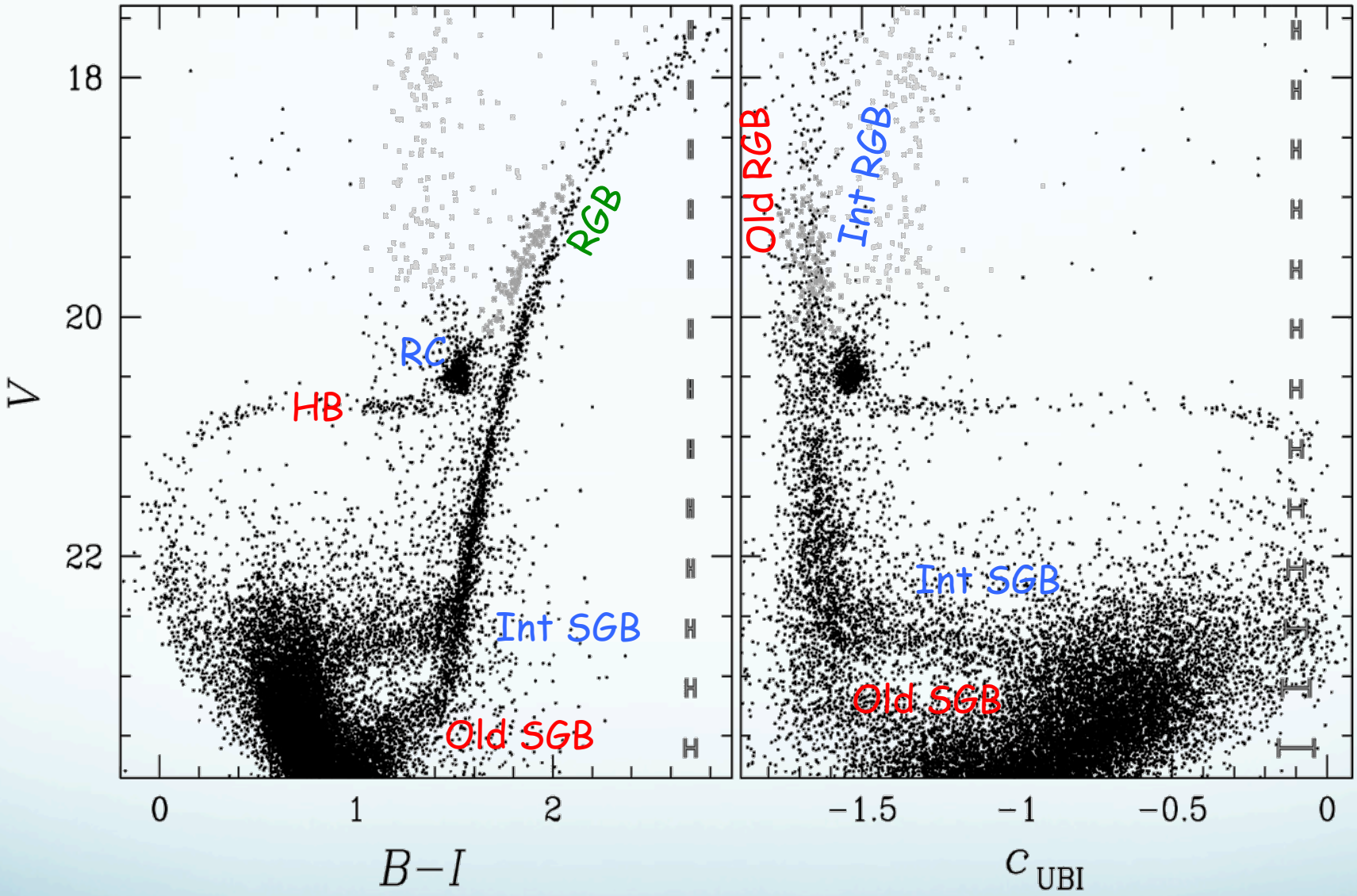
Complete coverage of central region (40'x55') + external pointing ~1.5°

Optical: *U, B, V, I*

Near Infrared: J, H, K

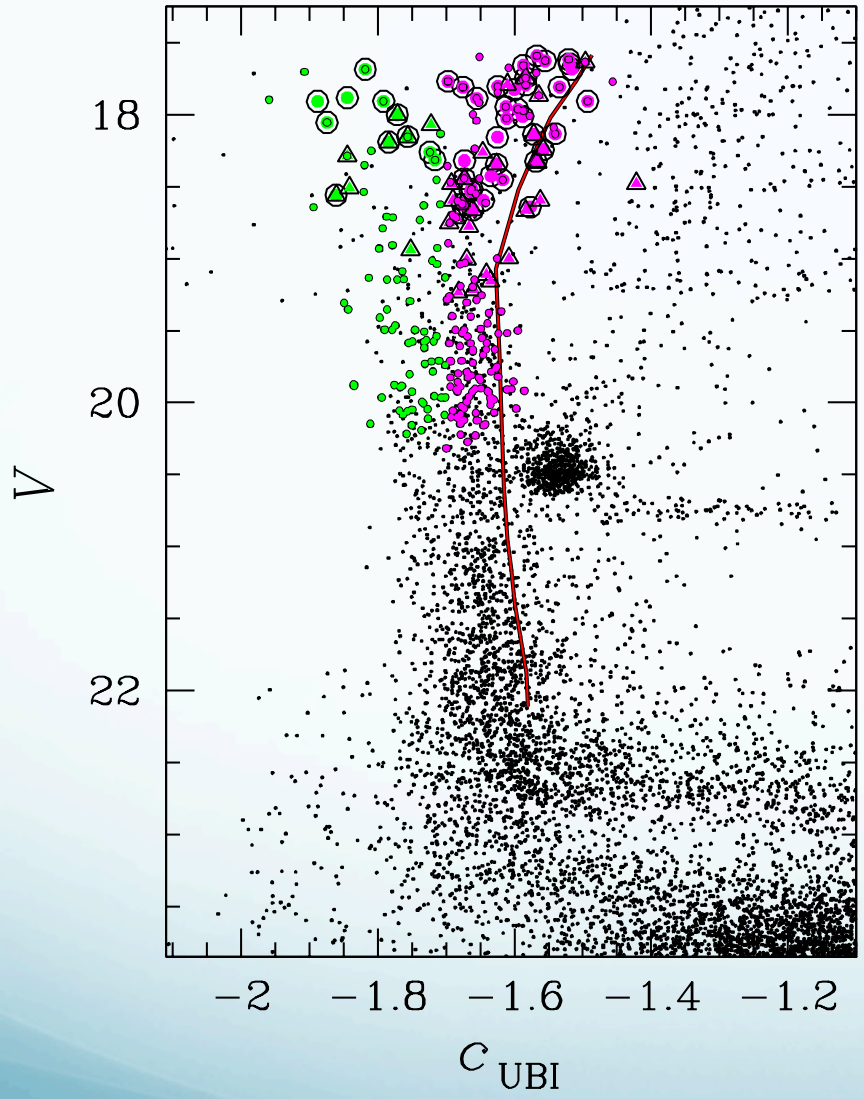

18
20
22
V
0
1
2
B−I
RGB
RC
HB
Int SGB
Old SGB

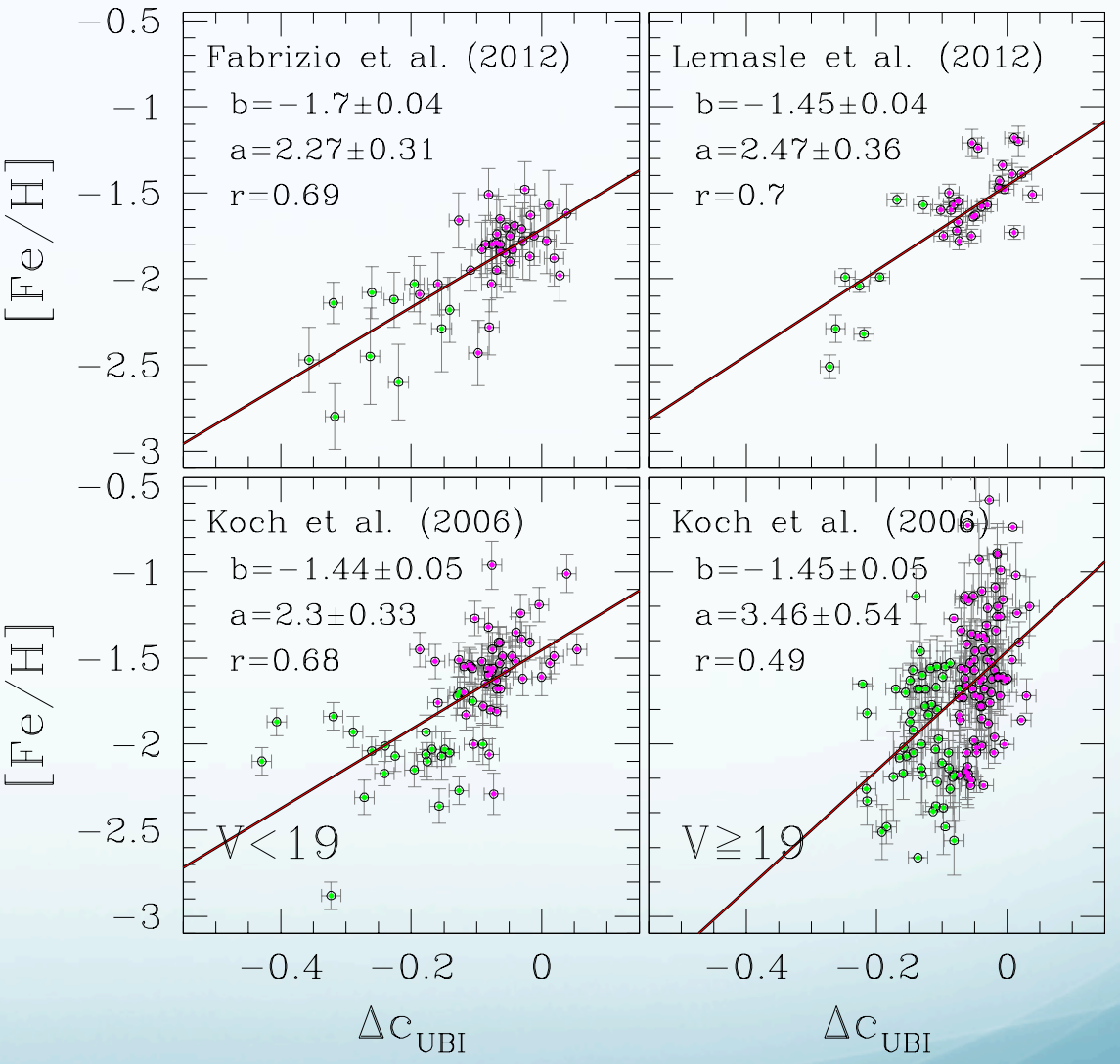
$c_{UBI}=(U-B)-(B-I)$



In **Monelli et al. 2014** (arXiv:1410.2124) we demonstrated that c_{UBI} is able to separate a significant fraction of the RGB of the two main Carina populations (old~12Gyr, interm.~4-8Gyr). See also Stetson+11

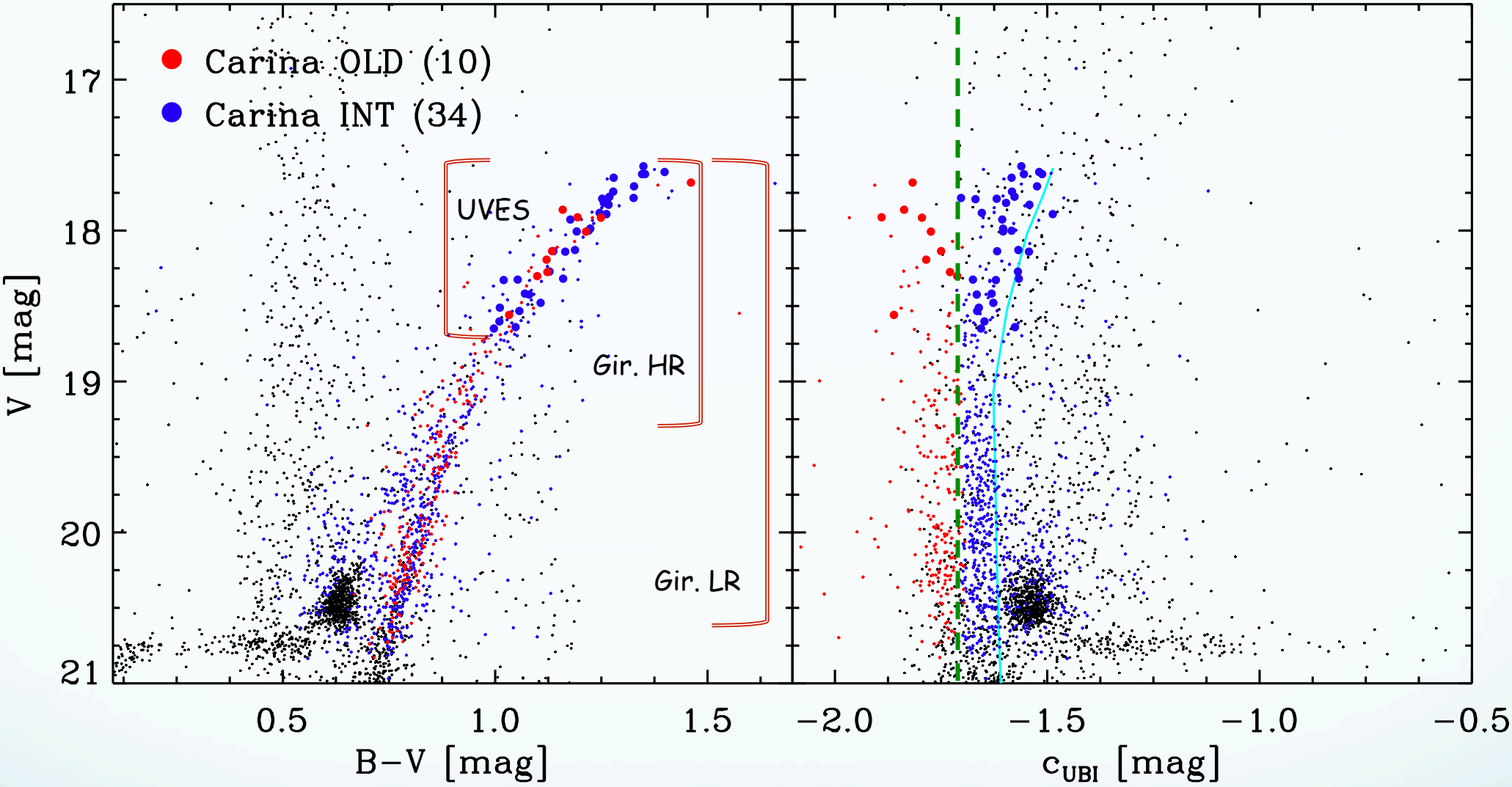
Toward the breaking of the age-metallicity degeneracy





Monelli+14, arXiv:1410.2124

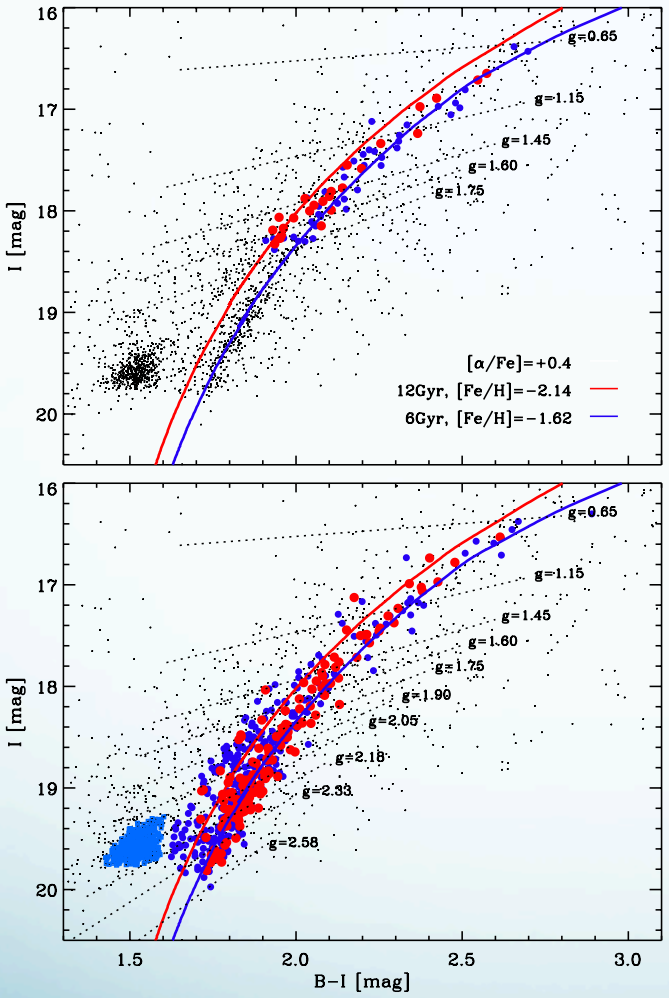
We correlate the pseudo-colour of RGB stars with their chemical properties, finding a significant trend between the iron content and the c_{UBI}.

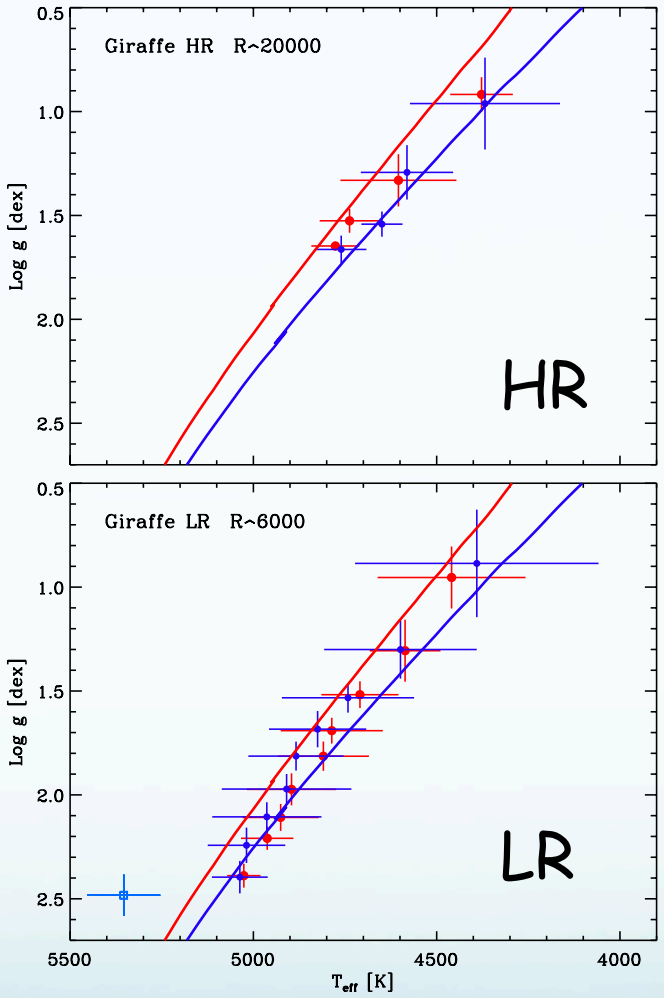


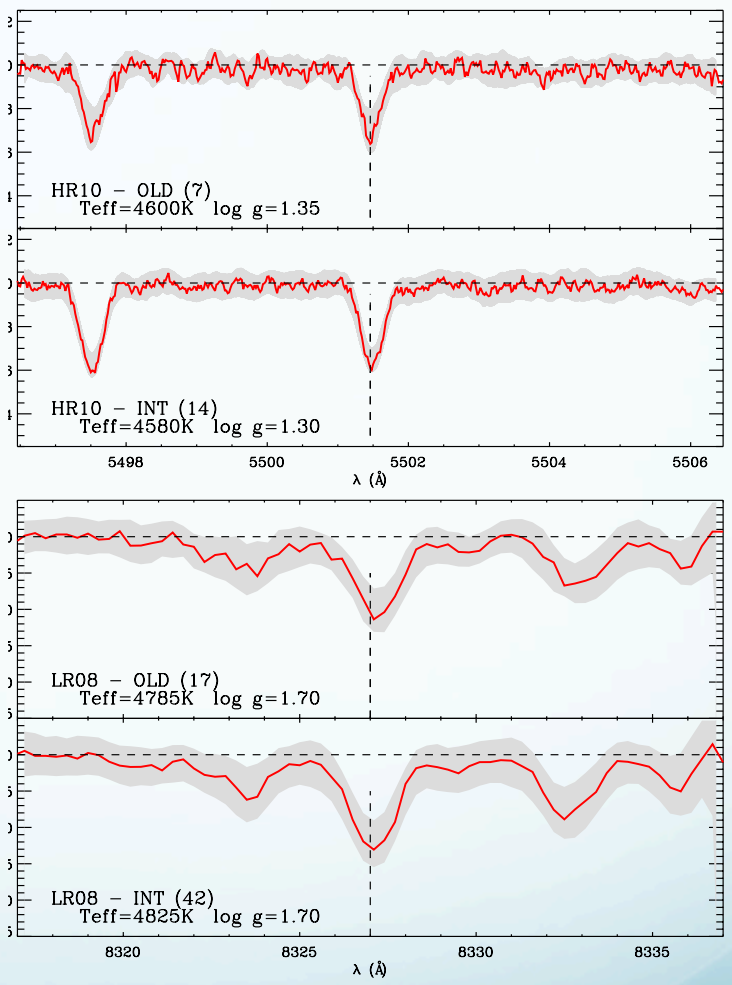
We have a powerful tool to separate and investigate, **independently**, the two populations

Fabrizio+14 in preparation

FLAMES/GIRAFFE Stacked spectra







SNR improves by a factor from 3 to 9
up to the RC magnitude level

Abundance measurements

Analysis performed line by line using "synth" or "abfind" in **MOOG** (Sneden 73, v.2014)

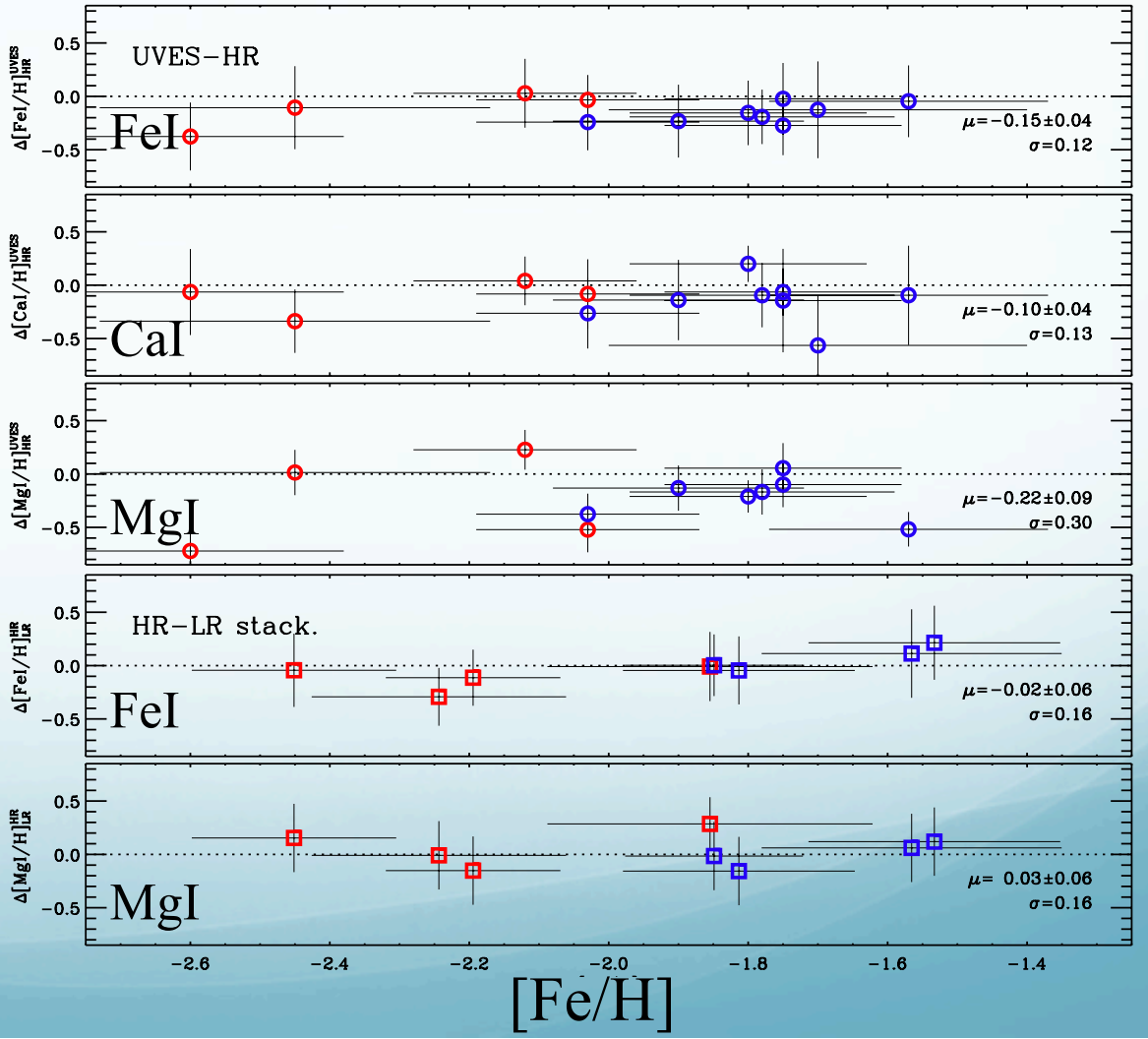
- ✓ Lines list & atomic data (VALD)
- ✓ Mod. atmosp. MARCS

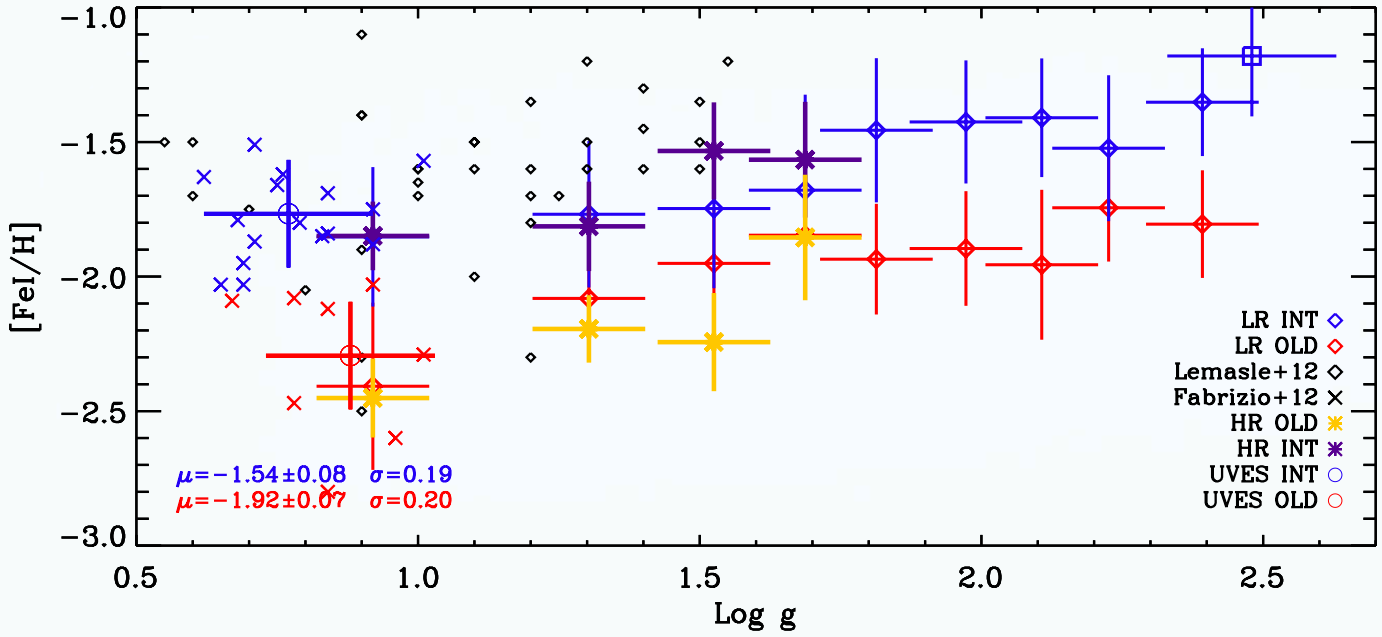
We applied selection criteria to reject lines:

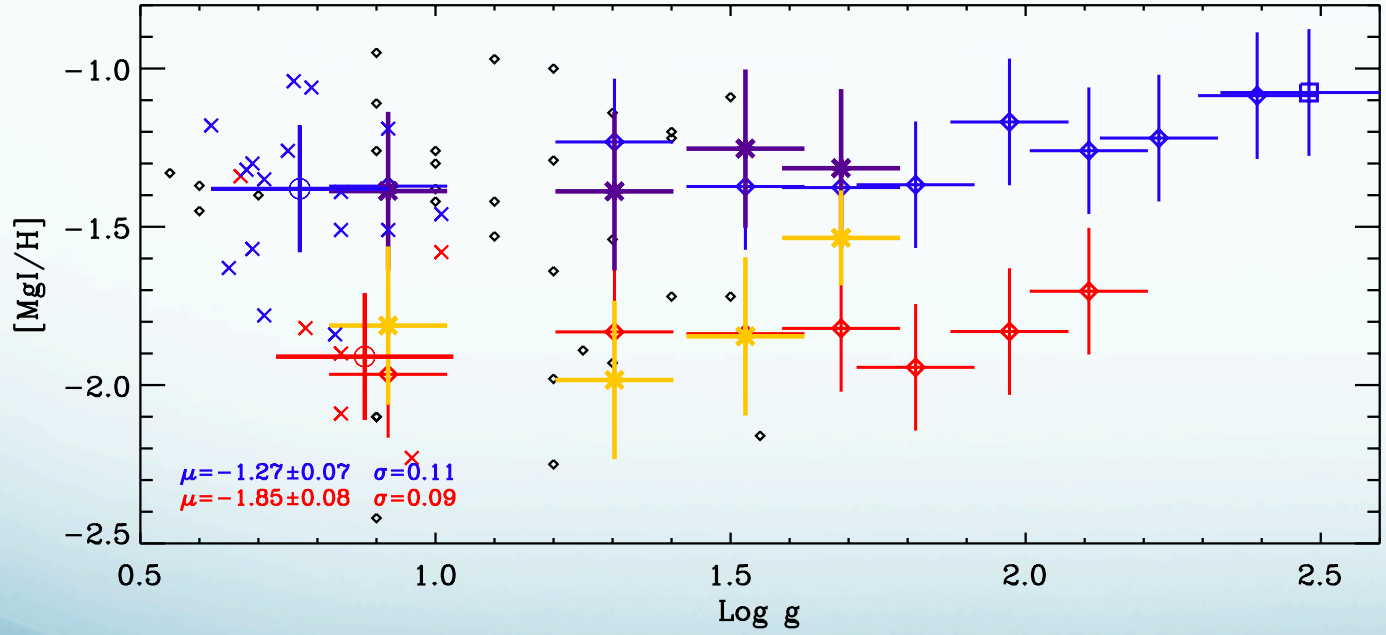
- × Saturated
- × Weak lines
- × Blended
- × Contaminated

Instrument	[Fe/H]	[α/Fe]
UVES	Synth. (Fabrizio+12)	EW
Giraffe HR	EW	EW
Giraffe LR	Synth.	Synth.

We obtained a good agreement (within 1σ) by comparing the results of stars in common in the various datasets (either individual and stacked); no trend of residuals

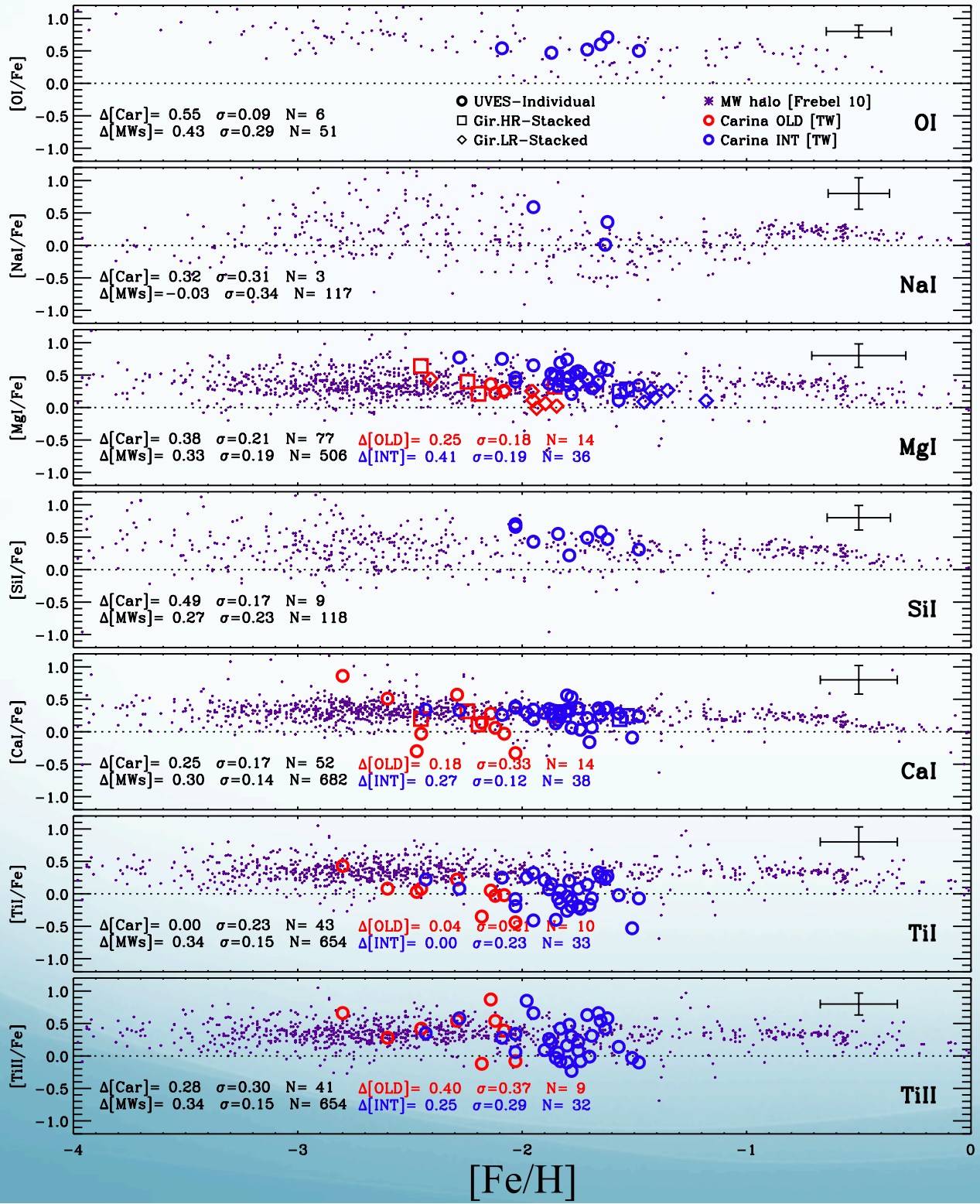






Measurements are compatible with literature values (Fabrizio+12, Lemasle+12).

The abundances separation between the two populations extends in the whole gravity (magnitude) range.

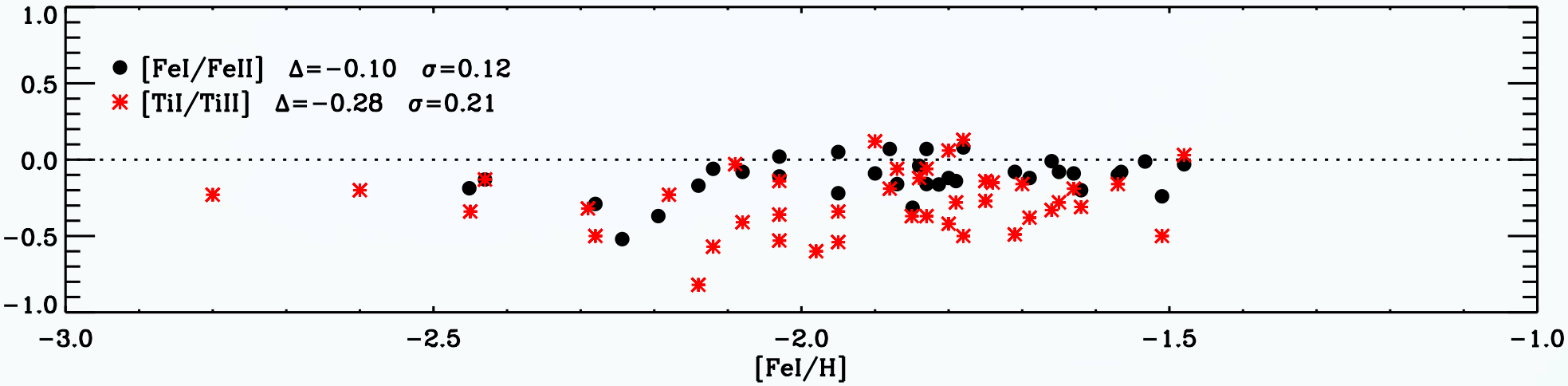


Accurate and homogeneous measurements of iron and α-el. for

- 44 UVES individual
- 8 Giraffe HR stacked
- 17 Giraffe LR stacked

Good agreement with the MW halo values in the explored iron range

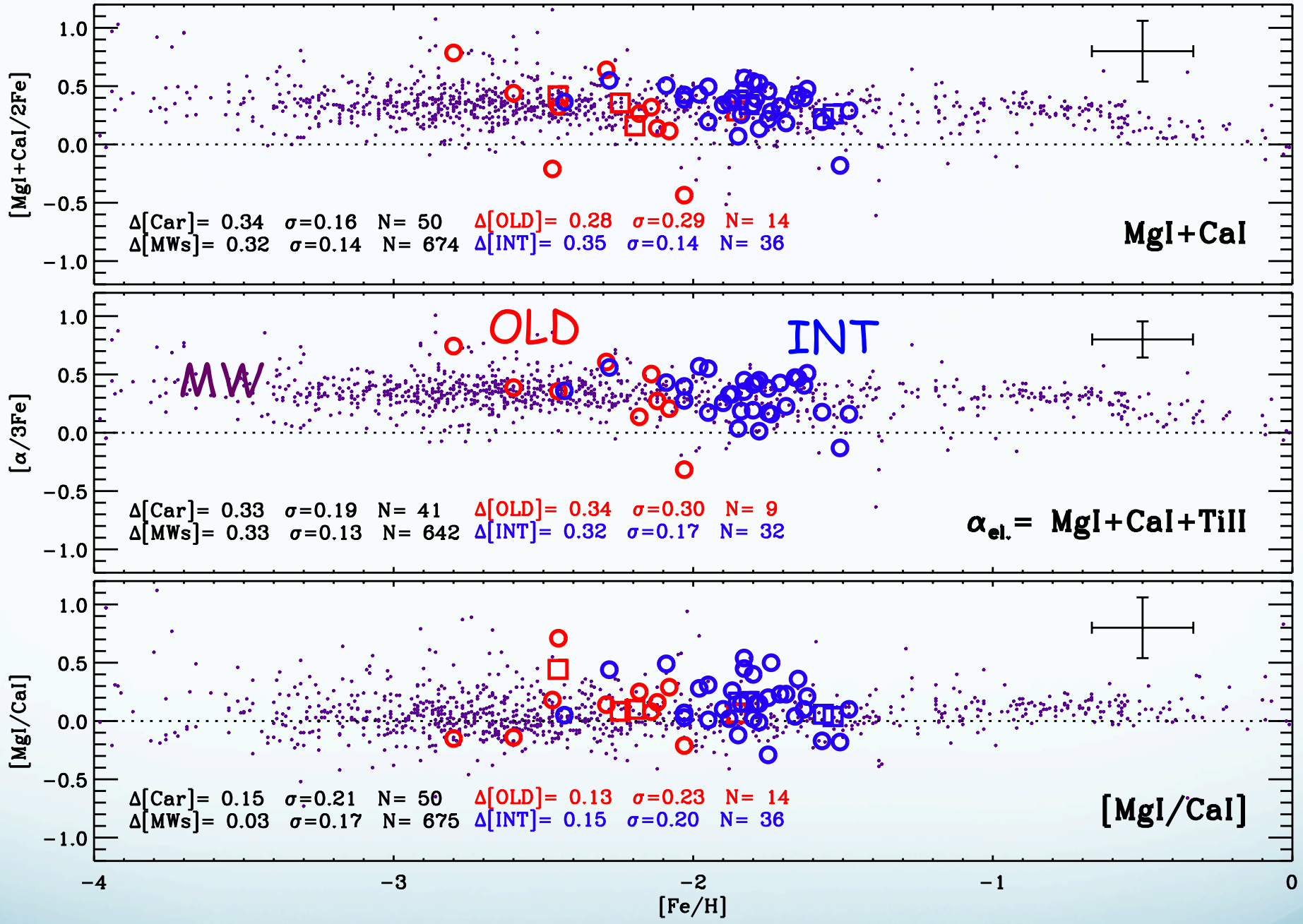
Empirical evidence of NLTE effects



NLTE computations show a significant relative difference between FeI/FeII and TiI/TiII theoretical abundances.

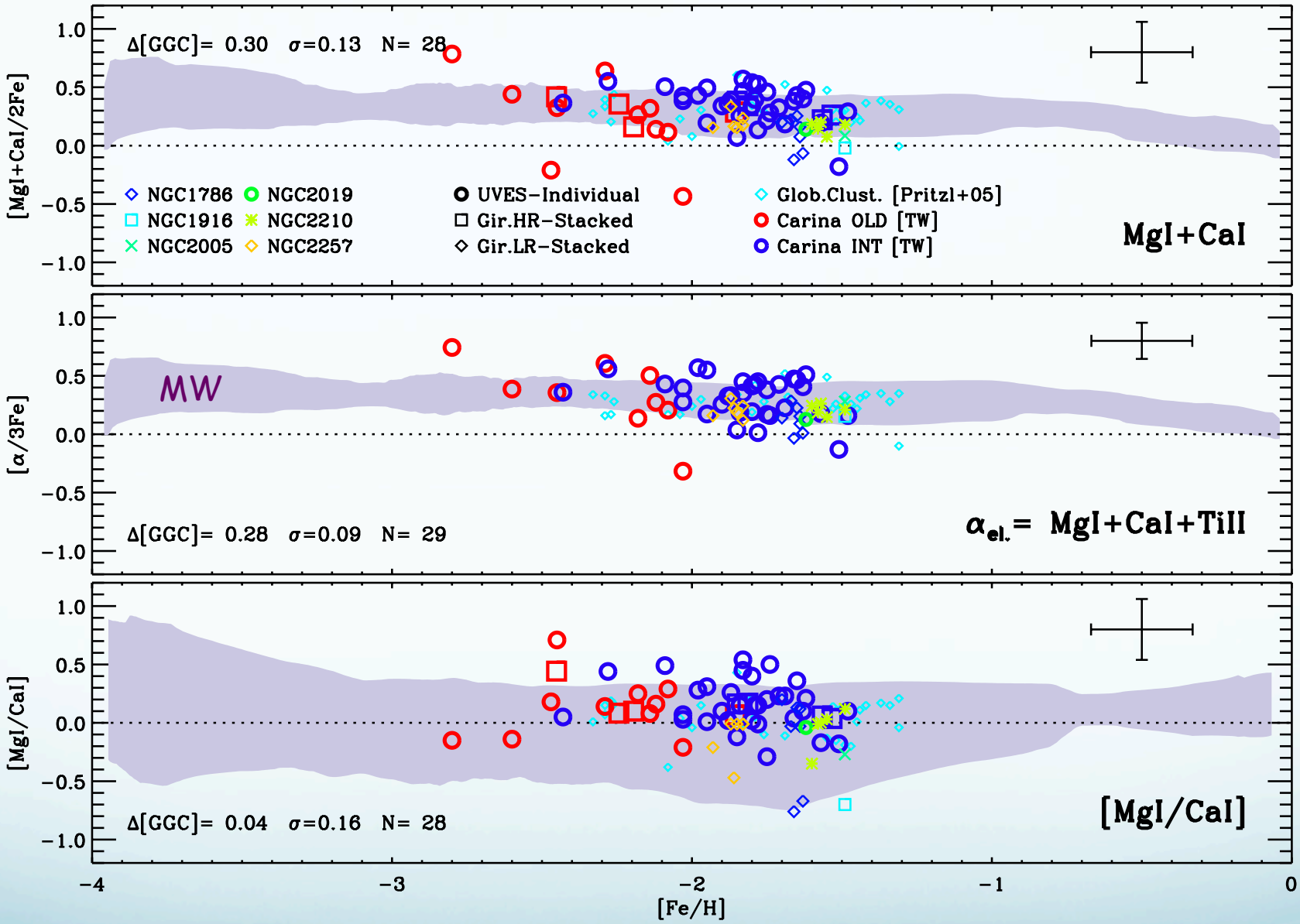
In agreement with the occurrence of NLTE effects in metal-poor RG atmospheres.

[Bergemann+11; McWilliam+13; Fabrizio+12]



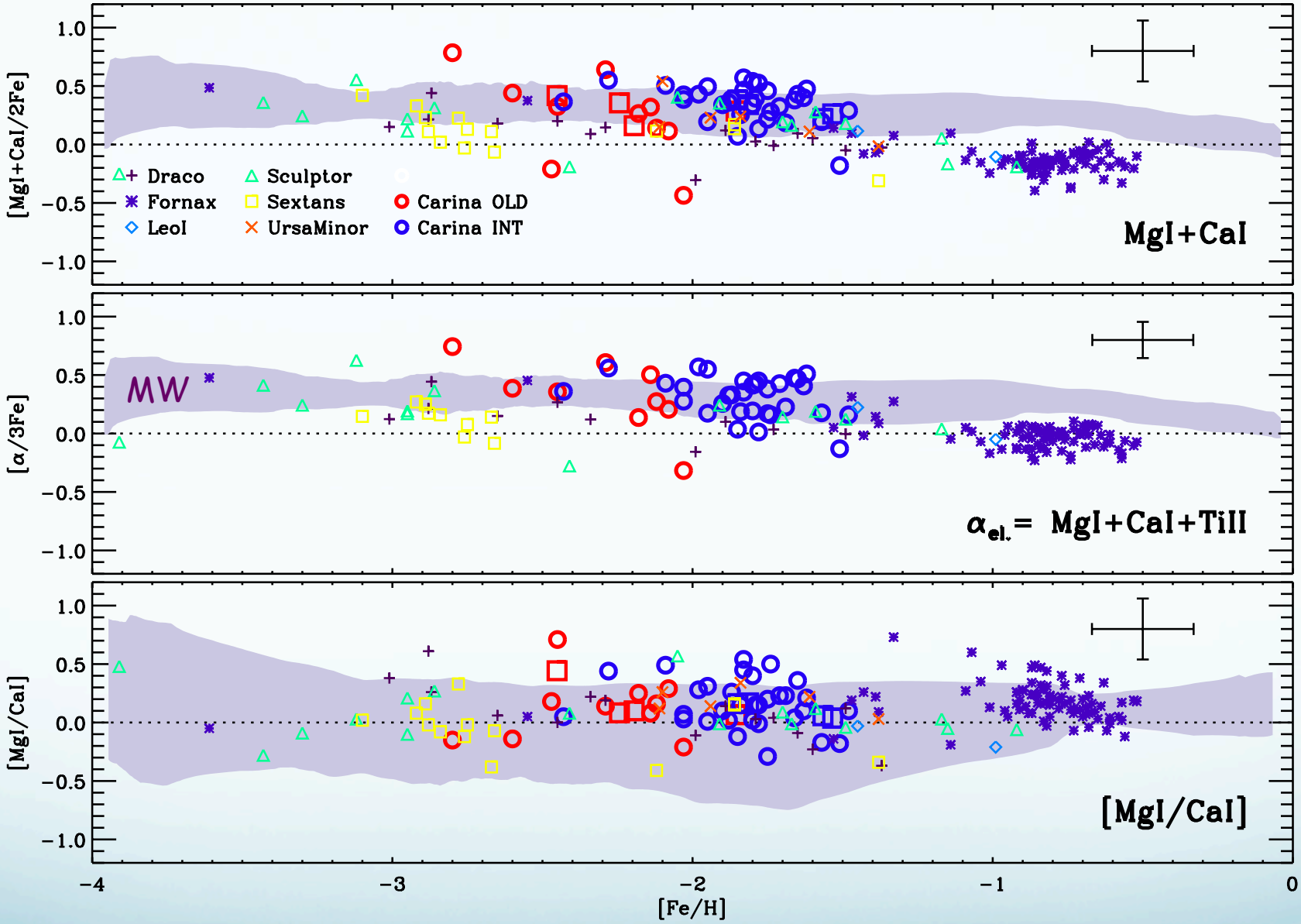
We do not found a robust evidence of the "knee" in the [α/Fe] distribution or a significant difference in abundances between the two populations, suggesting that the second star formation event was occurred in α-enriched gas. [e.g. Venn+12]

Comparison with Globular Cl. - MW & LMC



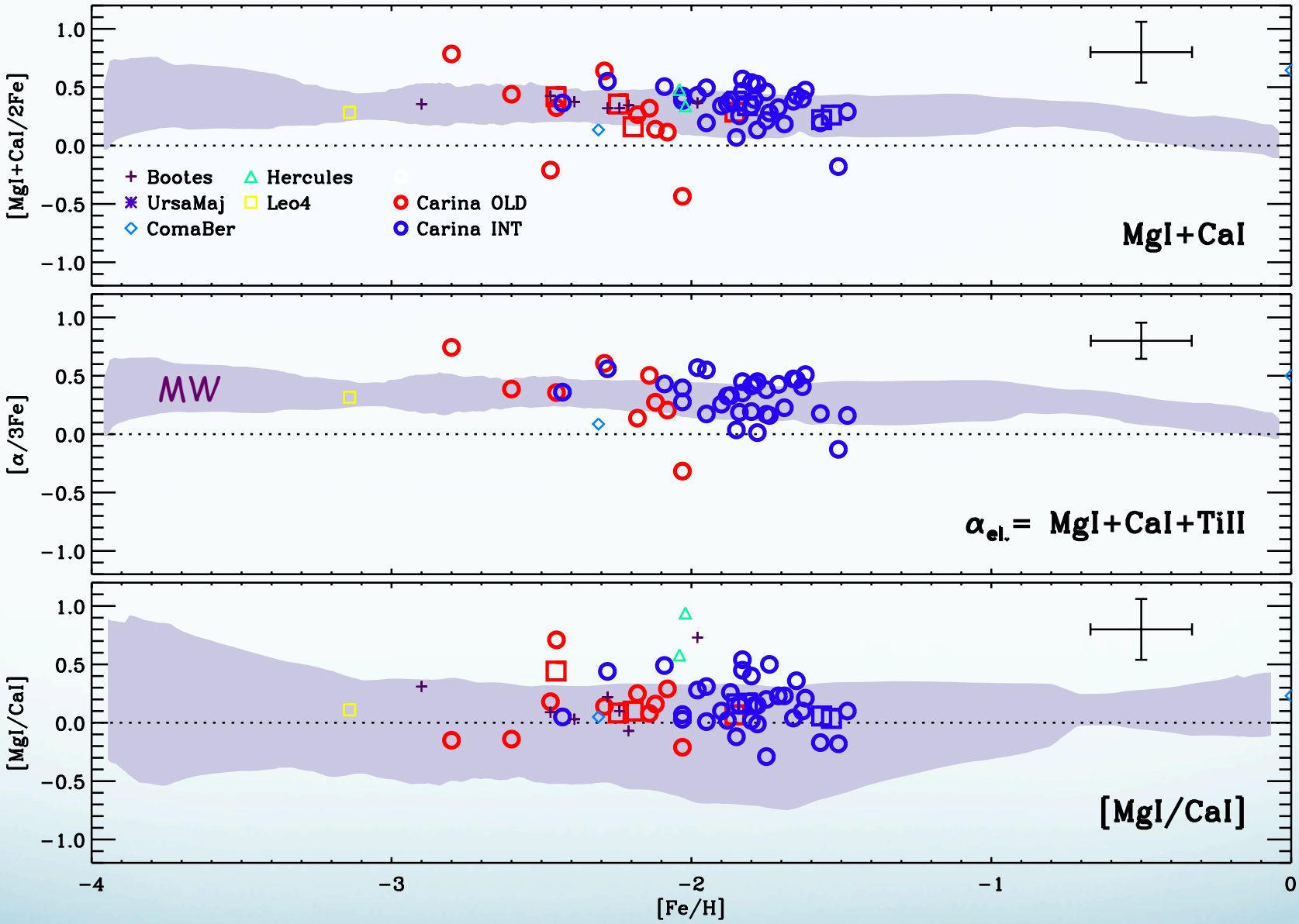
In the considerate iron range, a good agreement with α-el. abundances of GC was found

Comparison with LG dSphs



In the considerate iron range, we found a small enhancement of α-el. compared to the other dSphs.

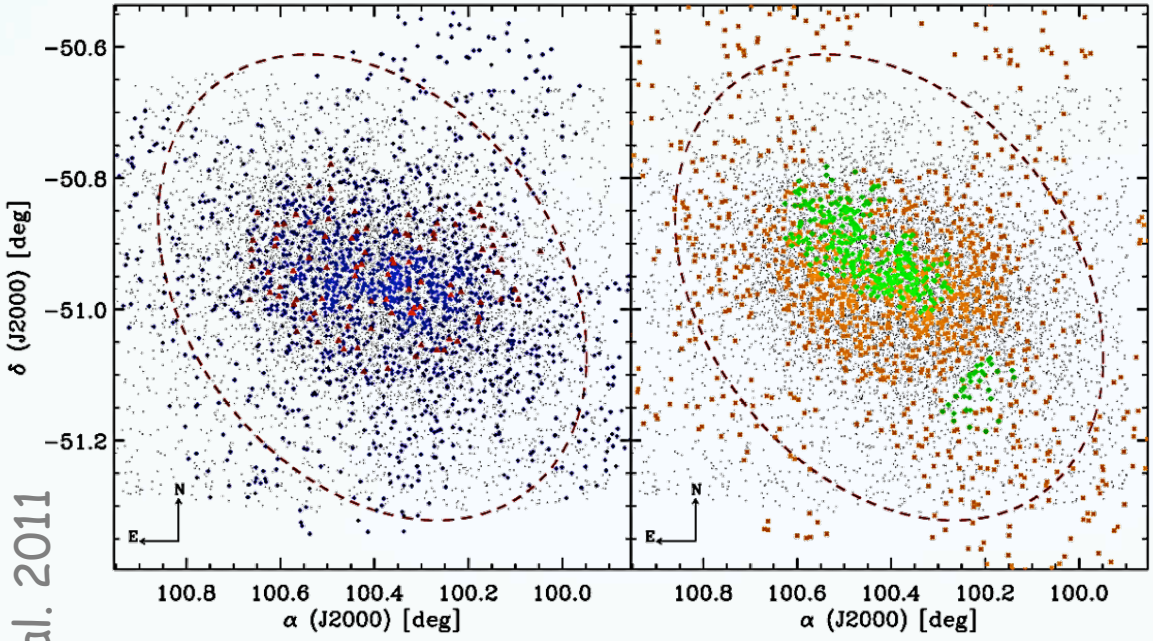
Comparison with UFDs

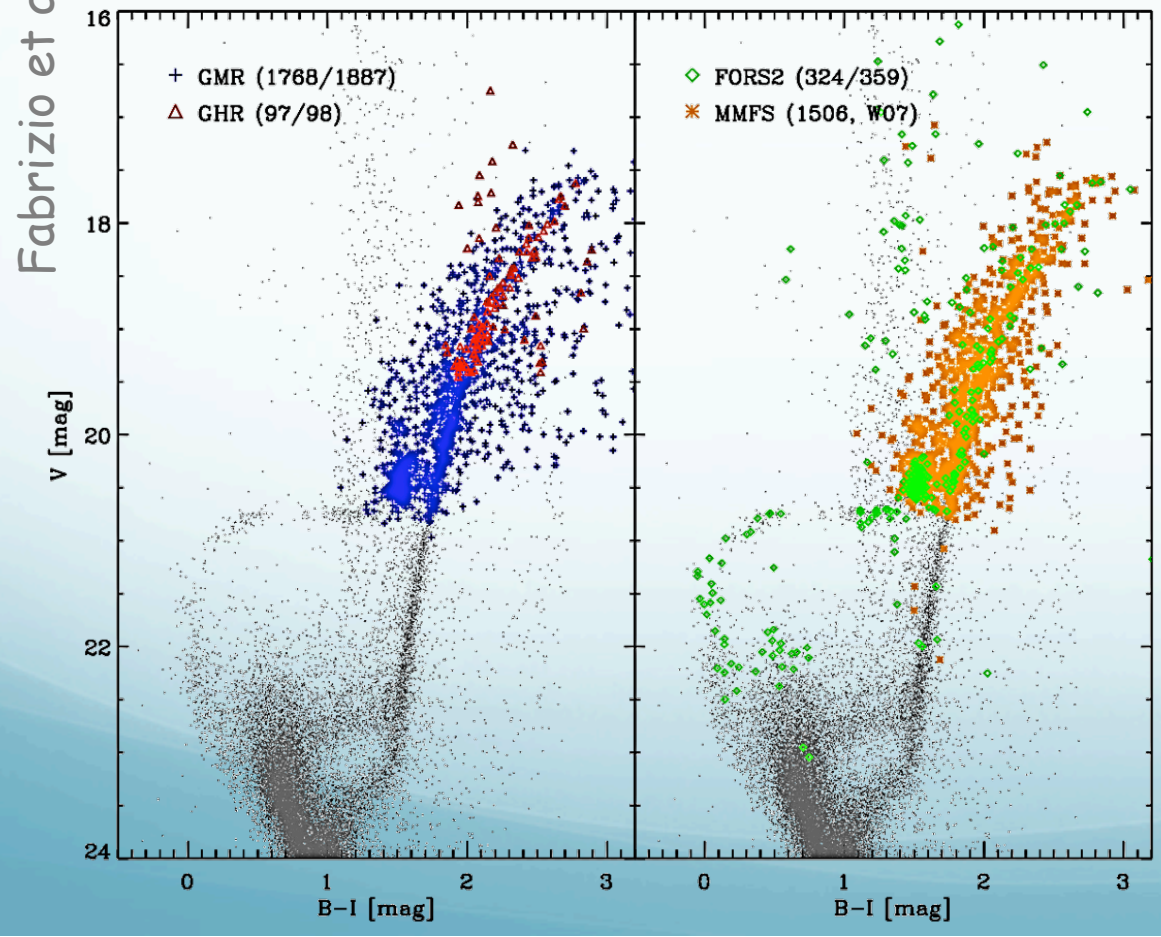


We found a good agreement with the abundances of UFDs

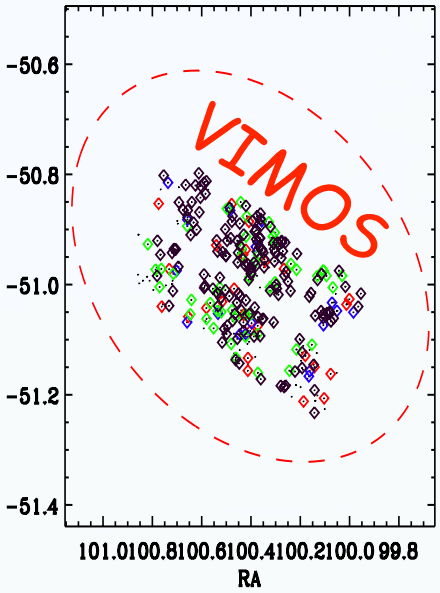
✗ Poor statistics

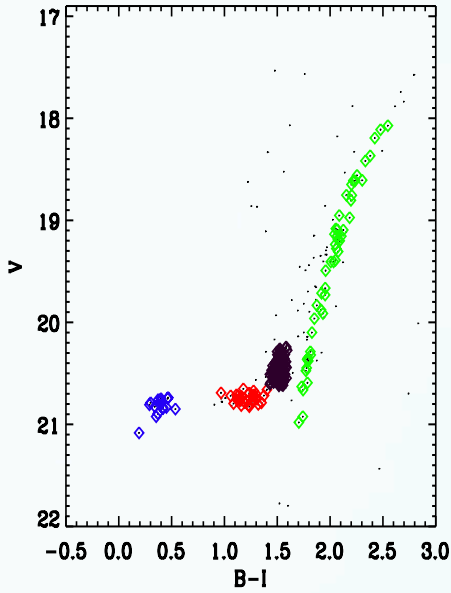
Kinematics





Fabrizio et al. 2011

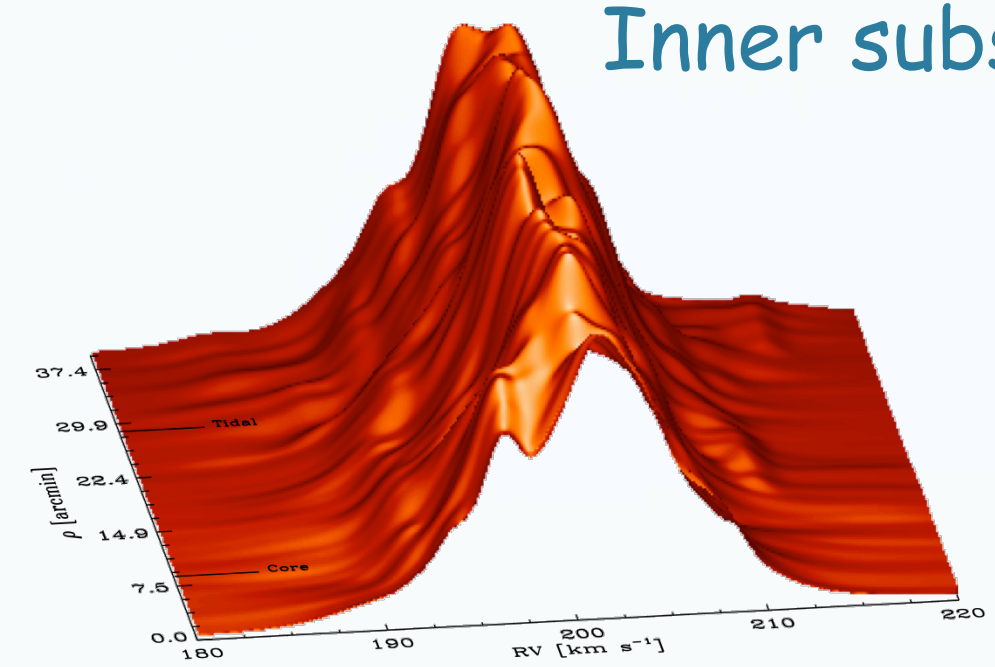


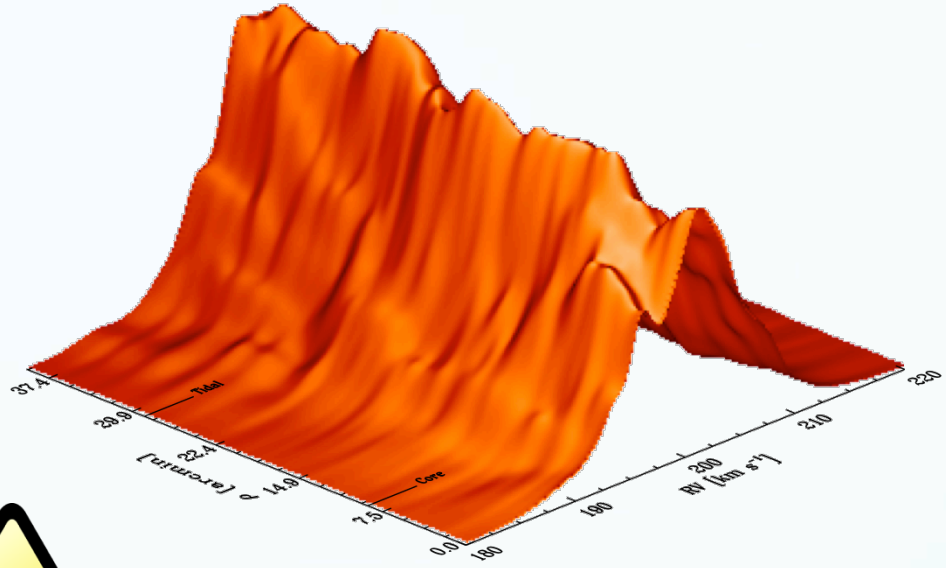


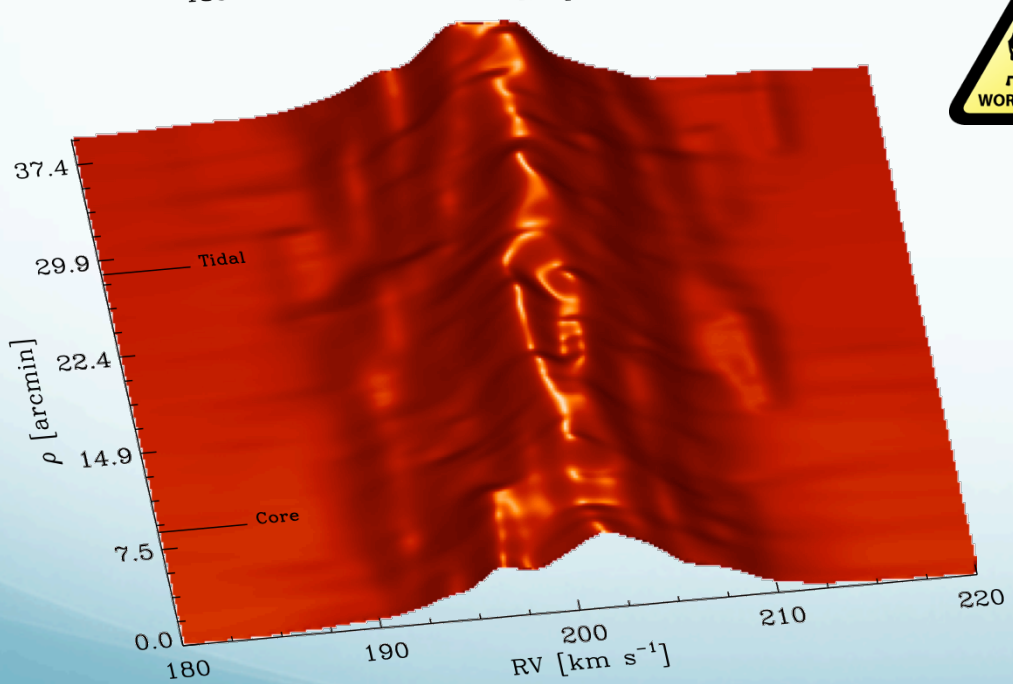
With the new VIMOS data, we collected more than 1440 RV measurements of Carina peak stars (2720 in the total sample).

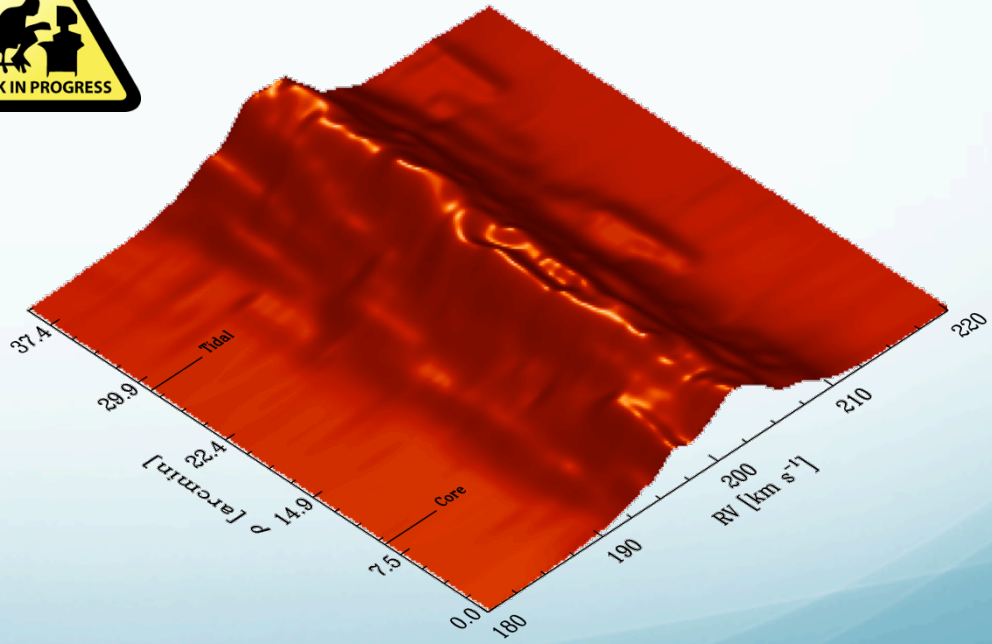
The spectroscopic dataset covers the entire body of Carina and beyond the tidal radius (up to ~1deg)

Inner substructures

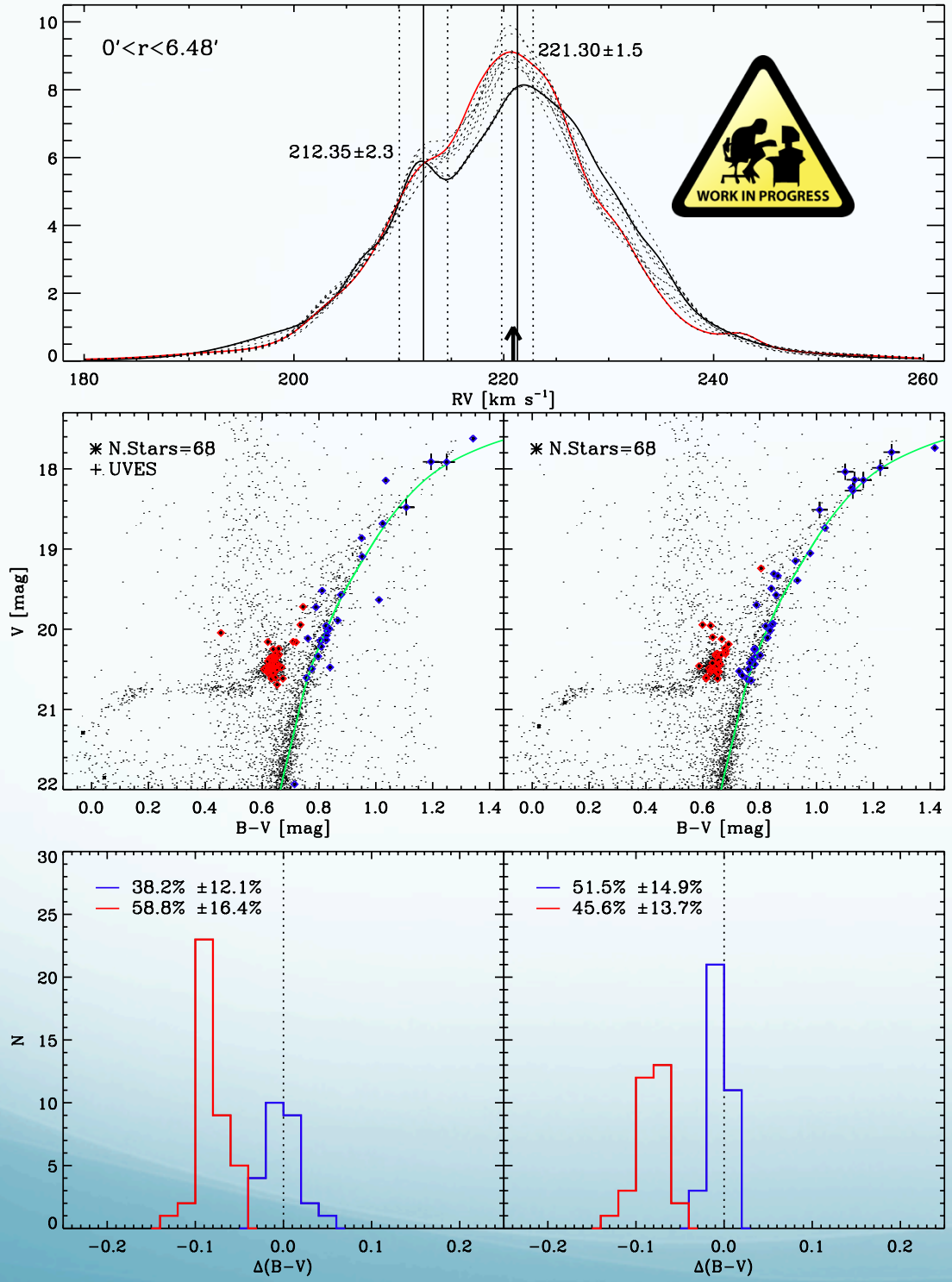








Fabrizio et al. 2014 in preparation



There is a mild evidence that the secondary peak with low velocity is mostly made by RC stars, i.e. the intermediate age (~6 Gyr) subpopulation of Carina.

Moreover, it is more metal-rich than the main peak.

The main peak as the other radial slices show the same percent of subpopulations.

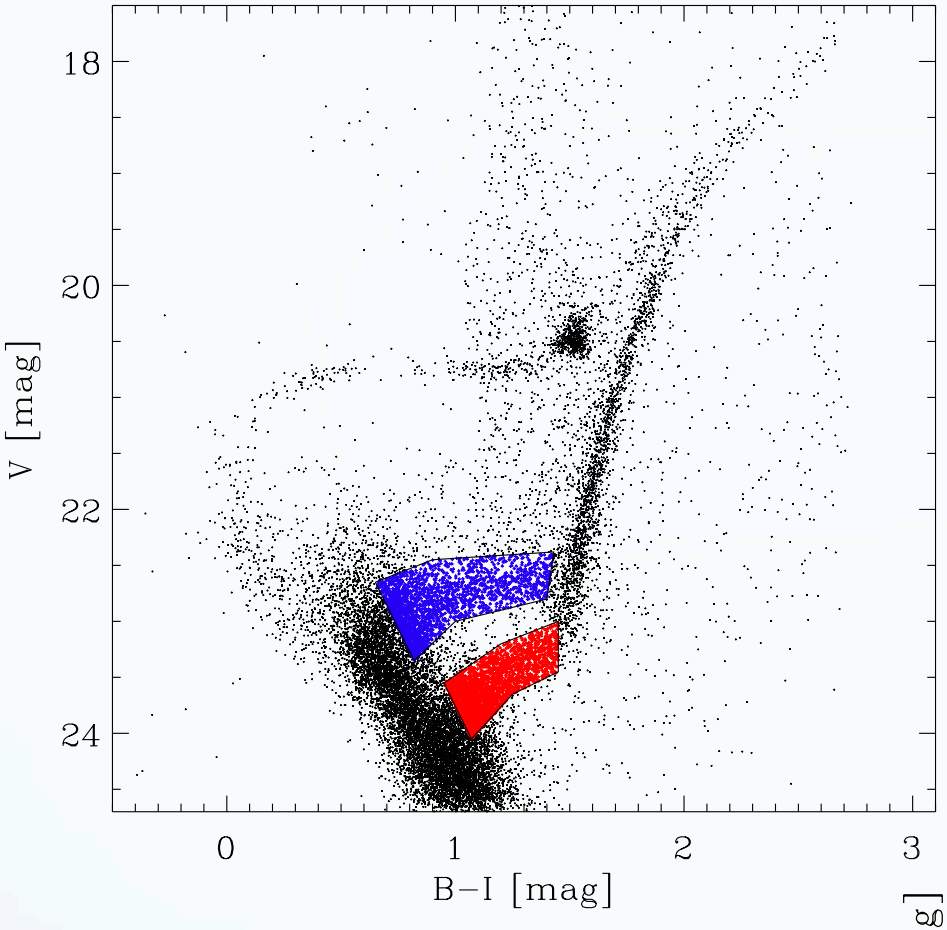
Conclusions

Abundances

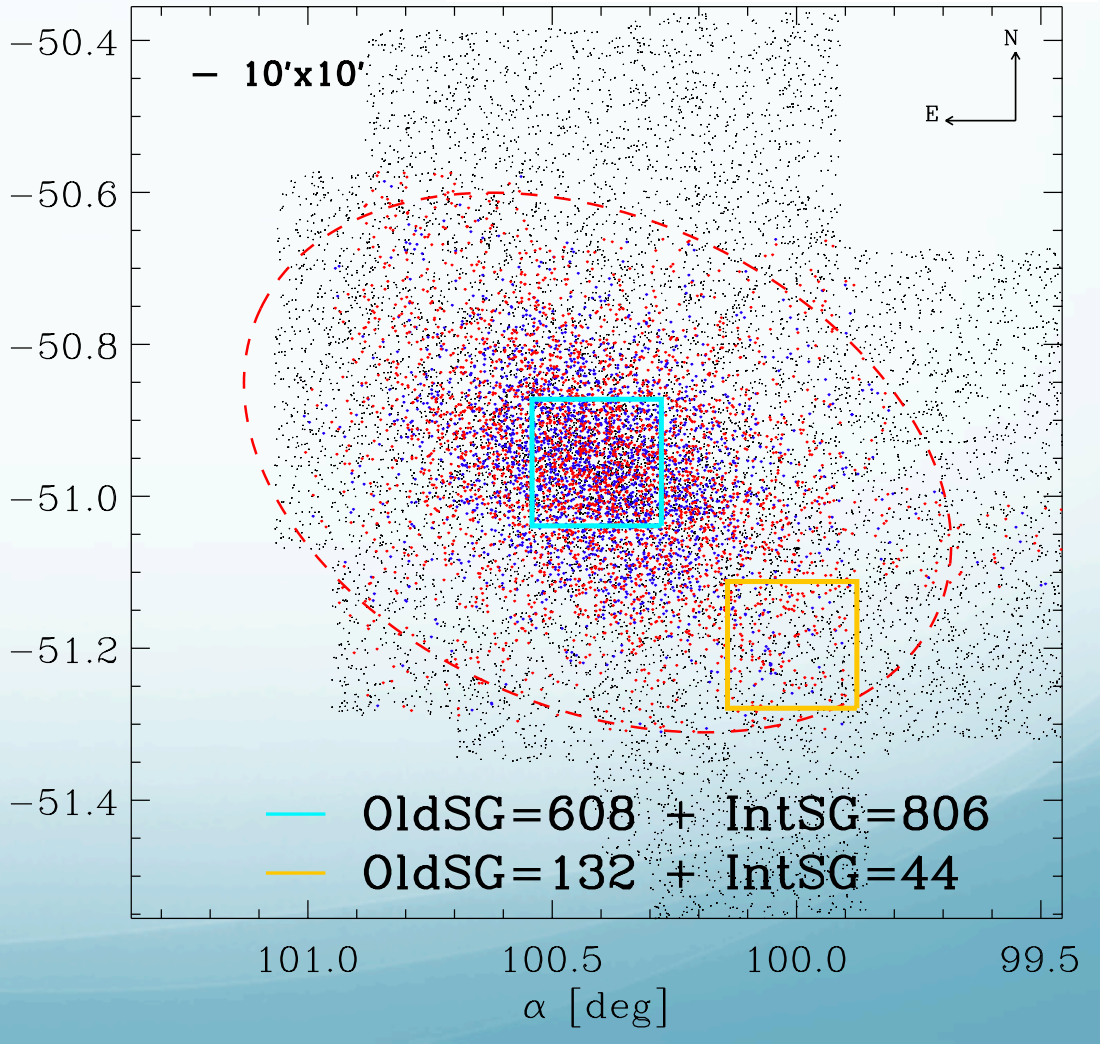
- c_{UBI} index: split two sub-populations in RGB
- Trend between iron and c_{UBI} index
- UVES individual spectra for 44 red giants
- GIRAFFE HR+LR for 8+17 stacked spectra along the RGB and RC
- Accurate and homogeneous measurements of Fe and α-elements
- The two populations do not show any significant difference in [α/Fe], suggesting that the second star formation event was occurred in α-enriched gas

Kinematics

- ~80% larger than any previous of Carina RV sample
- Evidence of substructure across the central region
- Mild evidence that the secondary peak with low velocity is mostly made by intermediate age population (RC stars)



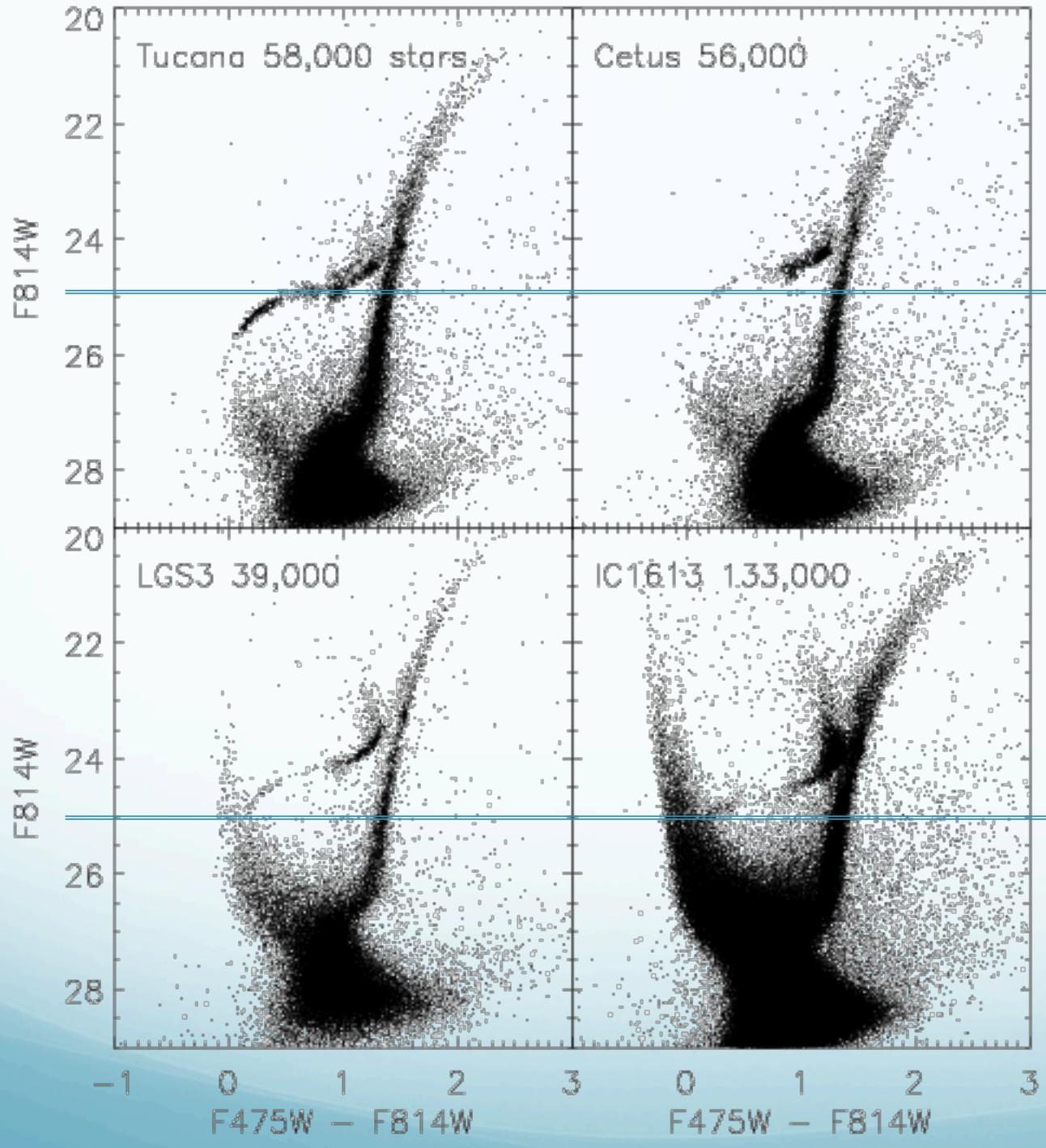
Future…in MOS@E-ELT

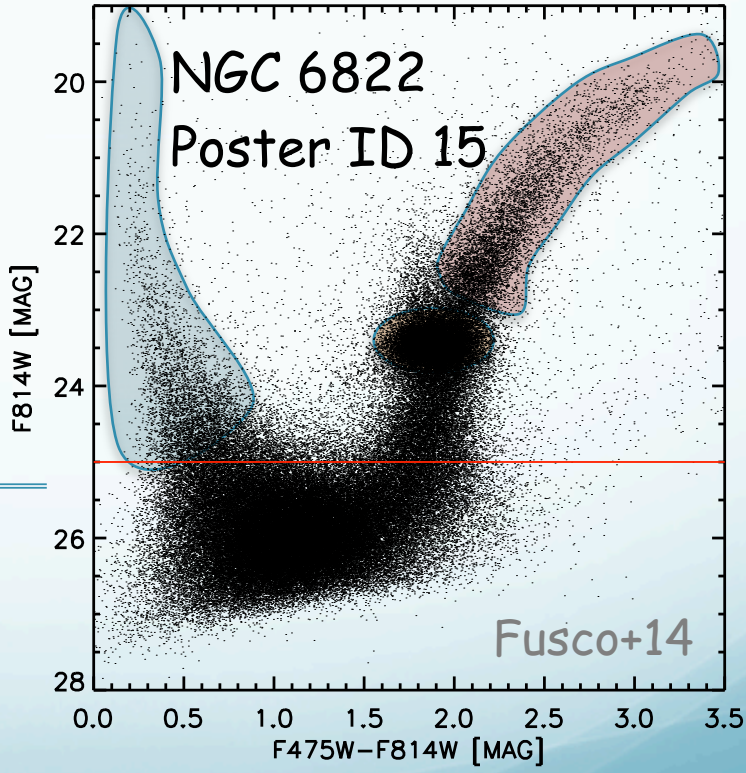


Requirements:

- FoV
- Multiplex
- Limiting magn.

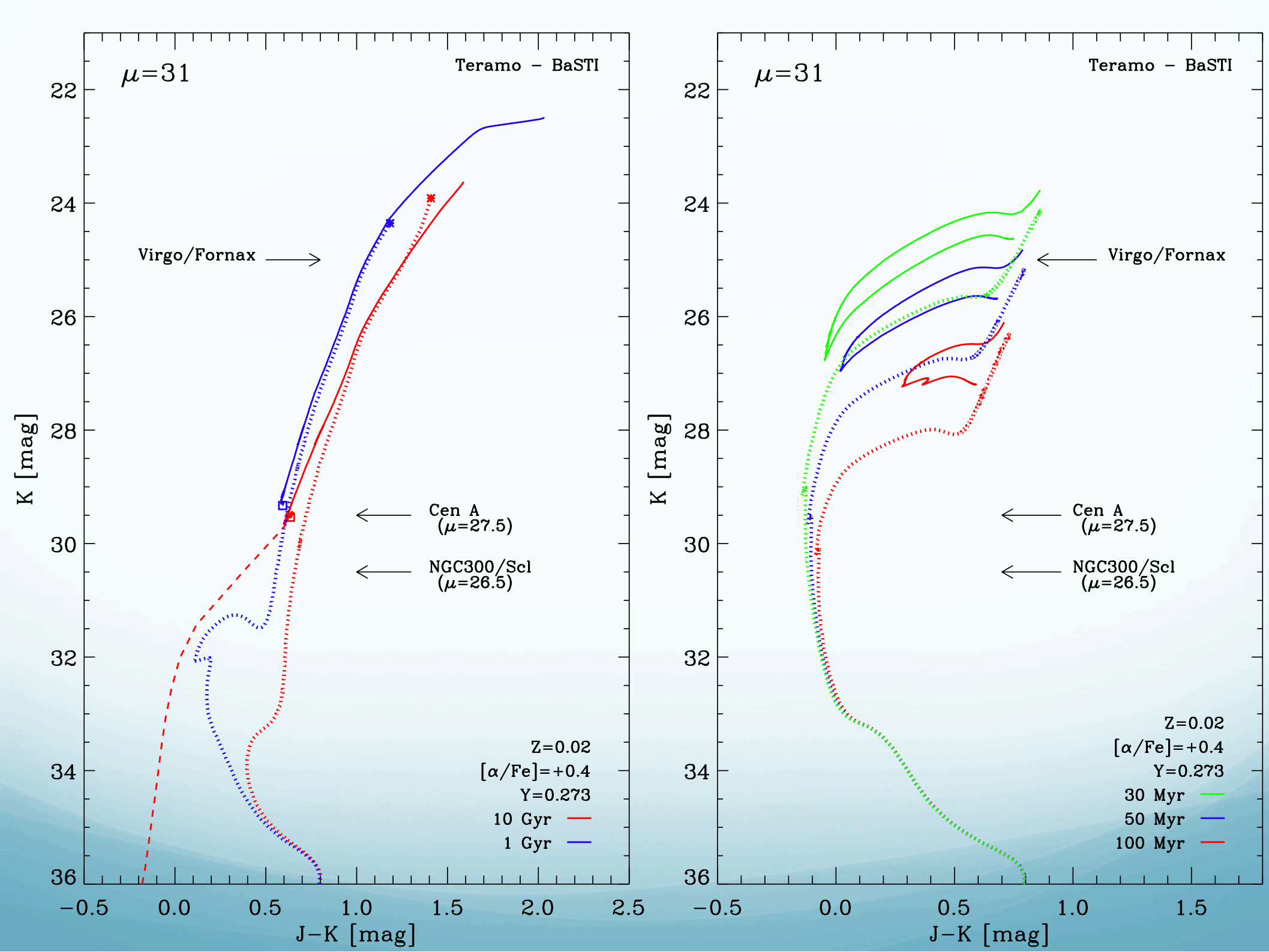
LG dwarfs in MOS@E-ELT



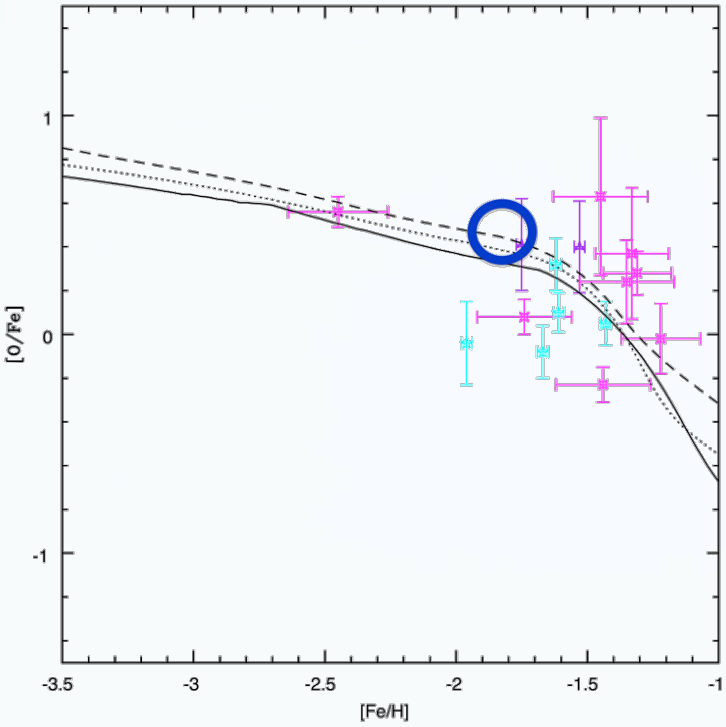


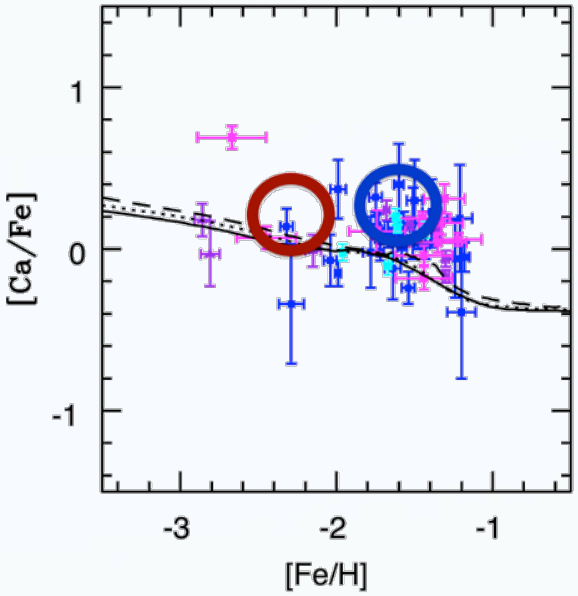
Bernanrd+12; Hidalgo+11; Monelli+10

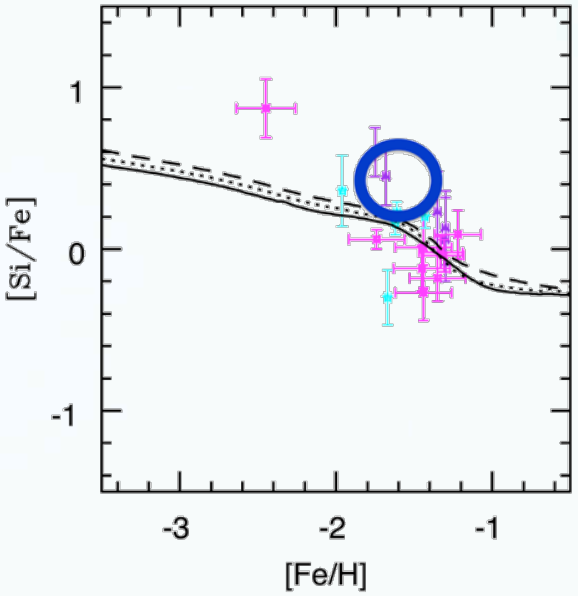
...and beyond...

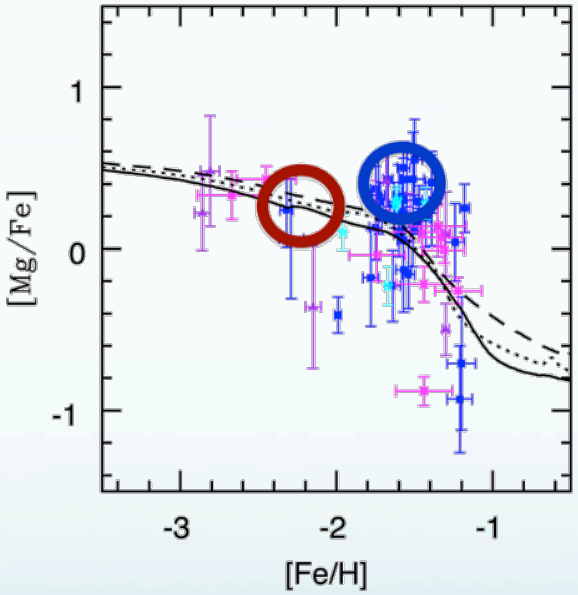

μ=31
Teramo – BaSTI
Virgo/Fornax
Cen A
(μ=27.5)
NGC300/Scl
(μ=26.5)
Z=0.02
[α/Fe]=+0.4
Y=0.273
10 Gyr
1 Gyr
K [mag]
J–K [mag]
22
24
26
28
30
32
34
36
−0.5
0.0
0.5
1.0
1.5
2.0
2.5
μ=31
Teramo – BaSTI
Virgo/Fornax
Cen A
(μ=27.5)
NGC300/Scl
(μ=26.5)
Z=0.02
[α/Fe]=+0.4
Y=0.273
30 Myr
50 Myr
100 Myr
K [mag]
J–K [mag]

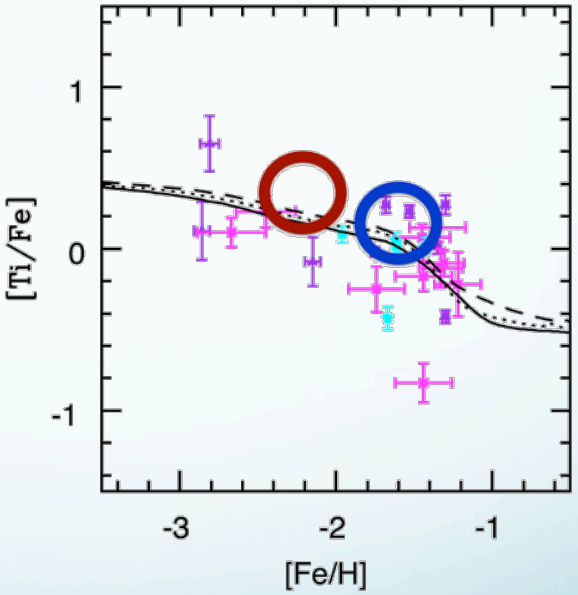
THANK YOU FOR YOUR ATTENTION

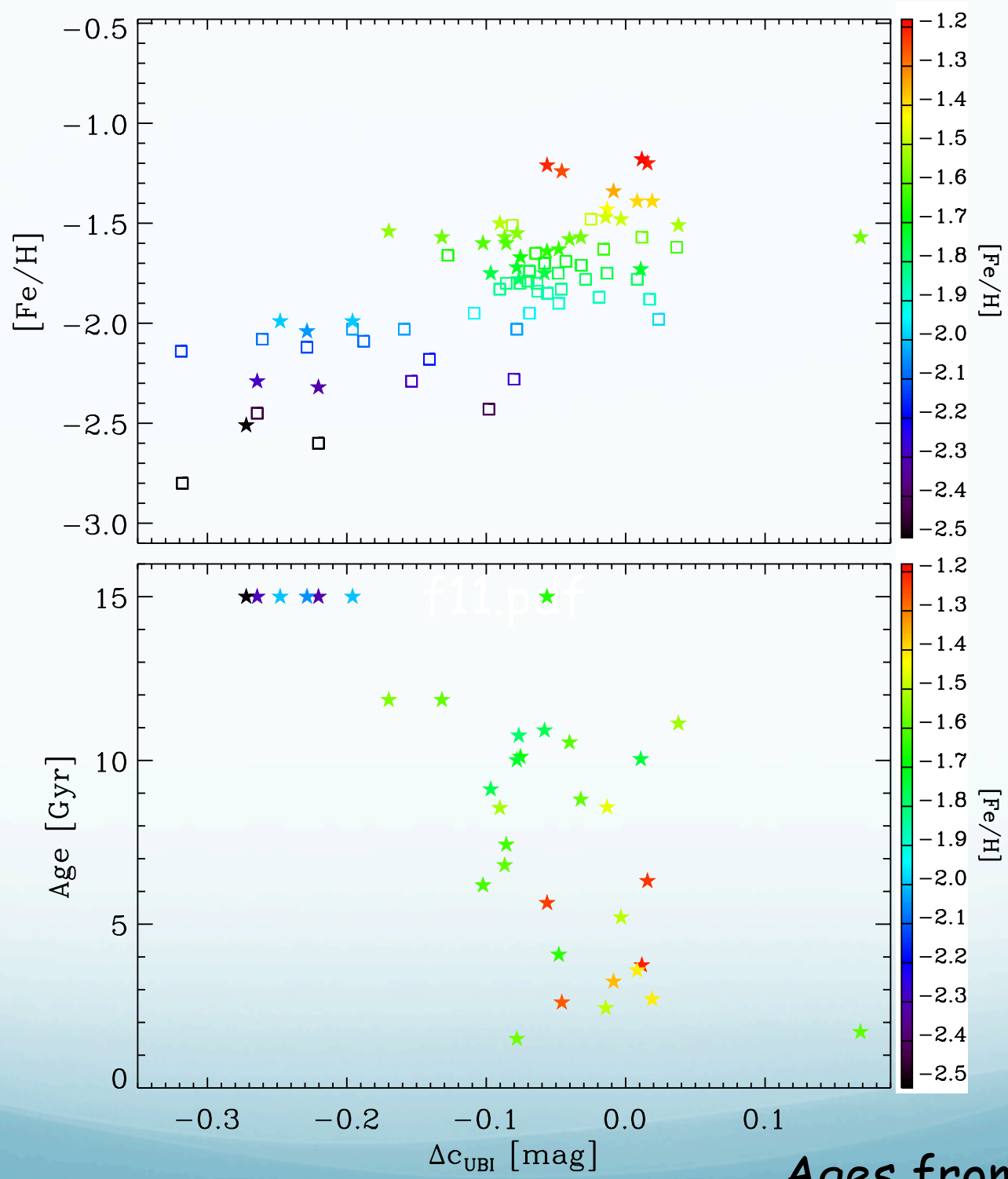

[O/Fe]
[Fe/H]
1
0
-1
-3.5
-3
-2.5
-2
-1.5
-1


[Ca/Fe]
[Fe/H]
1
0
-1
-3
-2
-1


[Si/Fe]
[Fe/H]
1
0
-1
-3
-2
-1


[Mg/Fe]
[Fe/H]
1
0
-1
-3
-2
-1


[Ti/Fe]
[Fe/H]
1
0
-1
-3
-2
-1

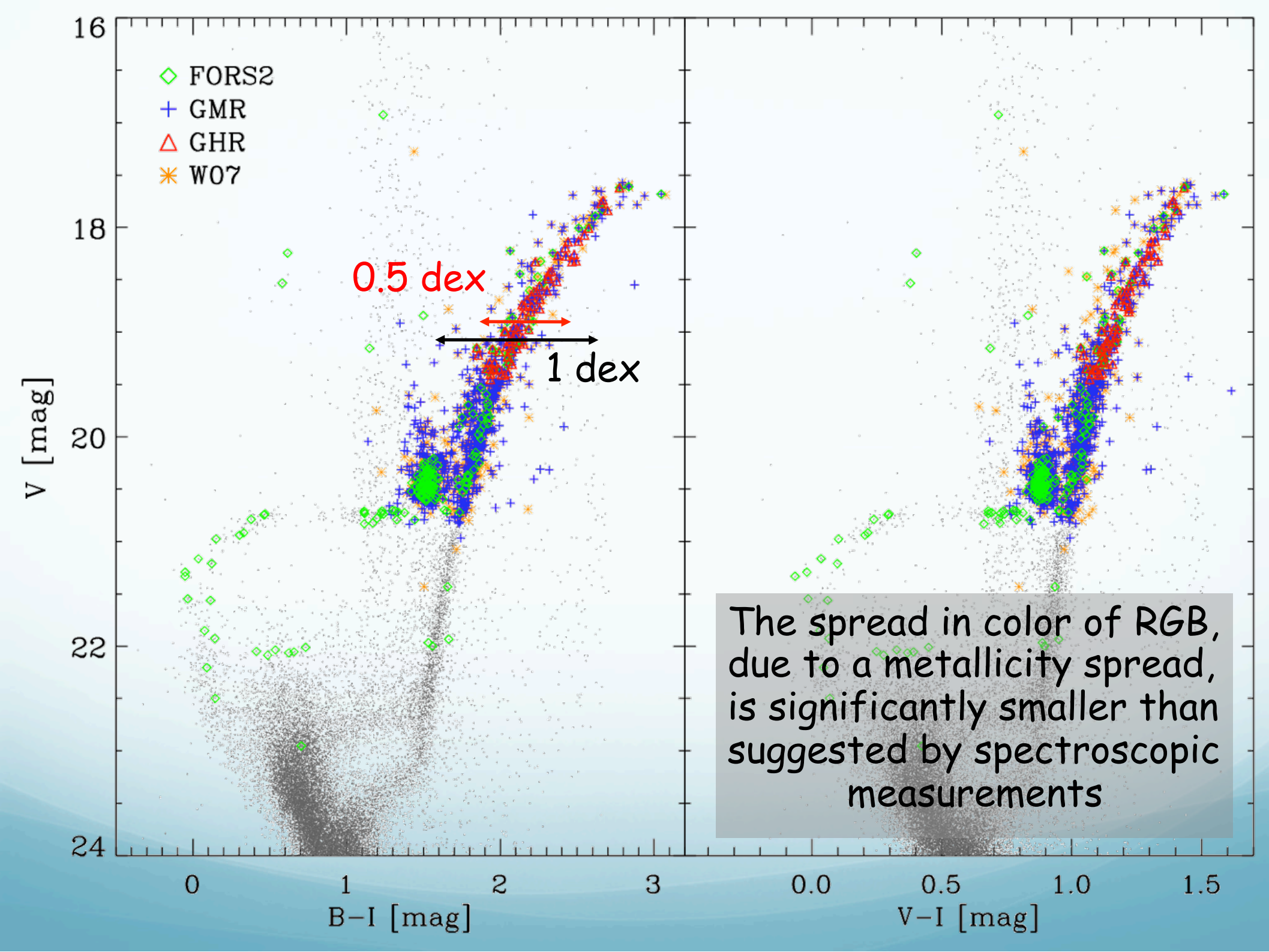


Ages from Lemasle+12

Requirements for MOS@E-ELT

Large FoV	> 7'x7' (10'x10')
High multiplex	> 100 - 200
Spatial res.	< 0.5 arcsec
Wide Res. range	2,000 – 20,000
Limiting magn.	I, K > 25 mag
S/N	~ 30 - 60

Simultaneous multiplexity between low/medium and high resolution fibers


FORS2
GMR
GHR
W07
0.5 dex
1 dex
V [mag]
B−I [mag]
V−I [mag]
16
18
20
22
24
0
1
2
3
0.0
0.5
1.0
1.5
The spread in color of RGB, due to a metallicity spread, is significantly smaller than suggested by spectroscopic measurements

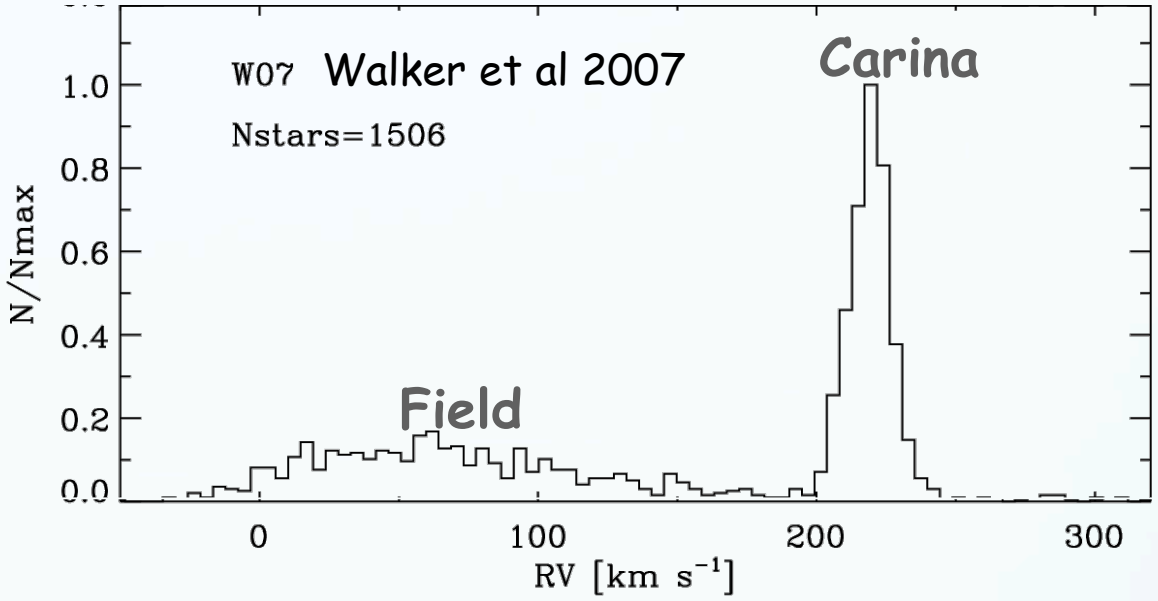
Carina: Kinematics

Velocity dispersion
-> total mass

Evidence of peculiarities in the RV distribution?

Substructures?

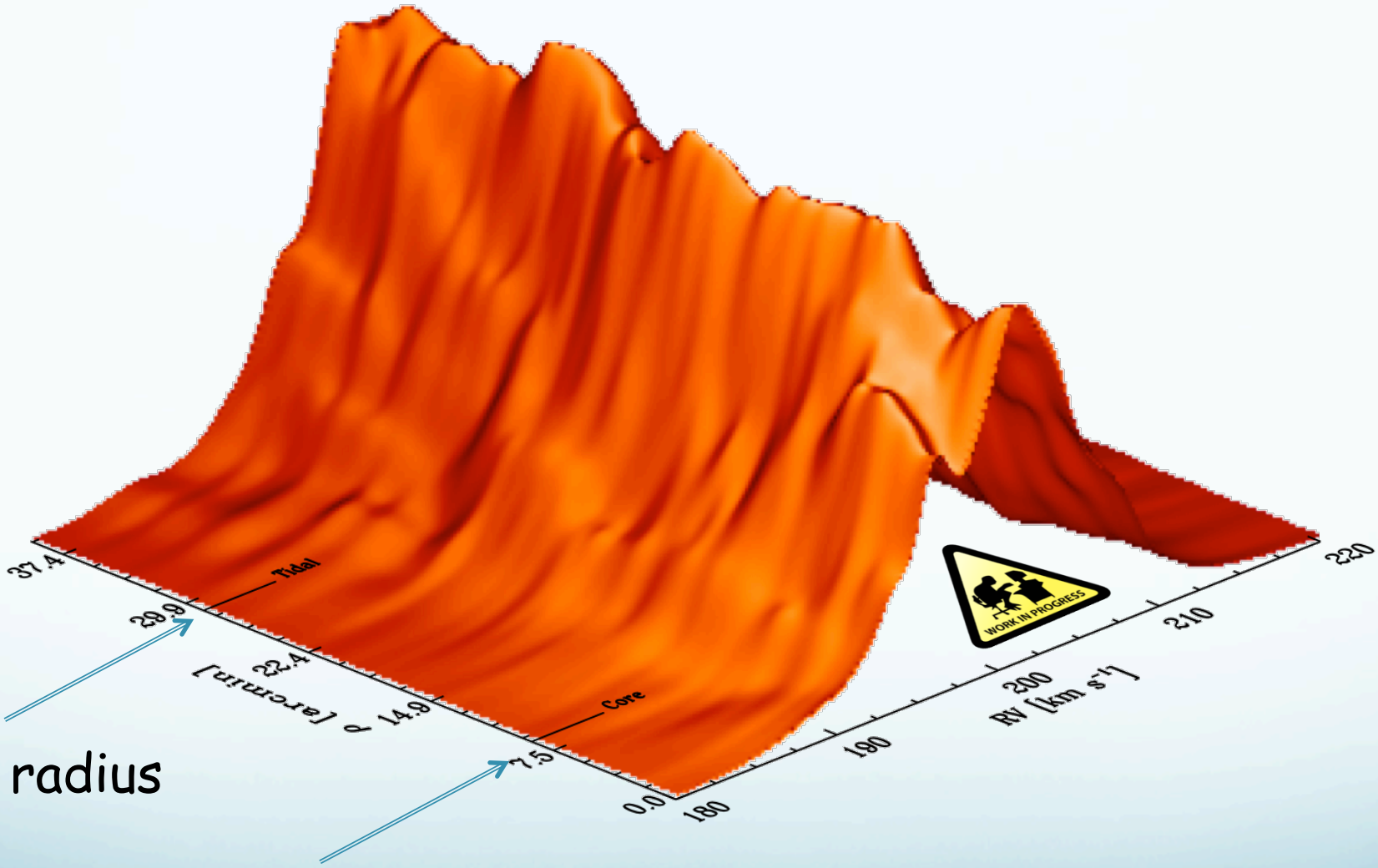
Tidal interaction?



Asymmetry in the RV distrib.

Need large sample of spectroscopic data covering entire body of galaxy and beyond

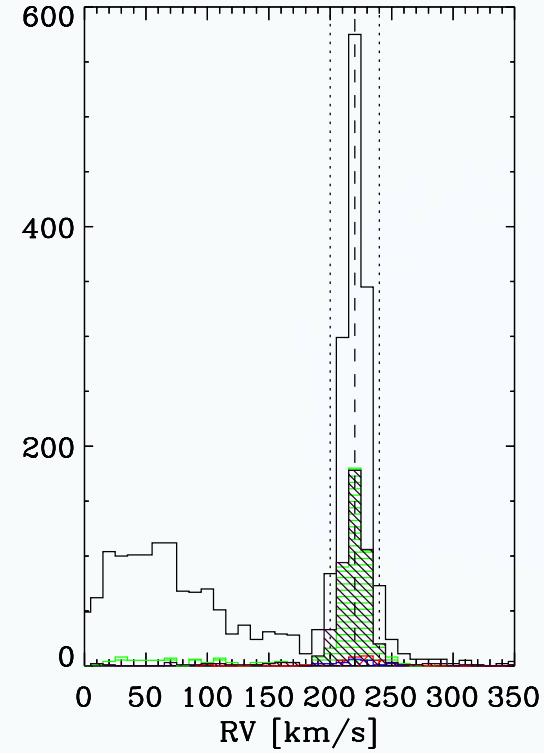
Inner substructures

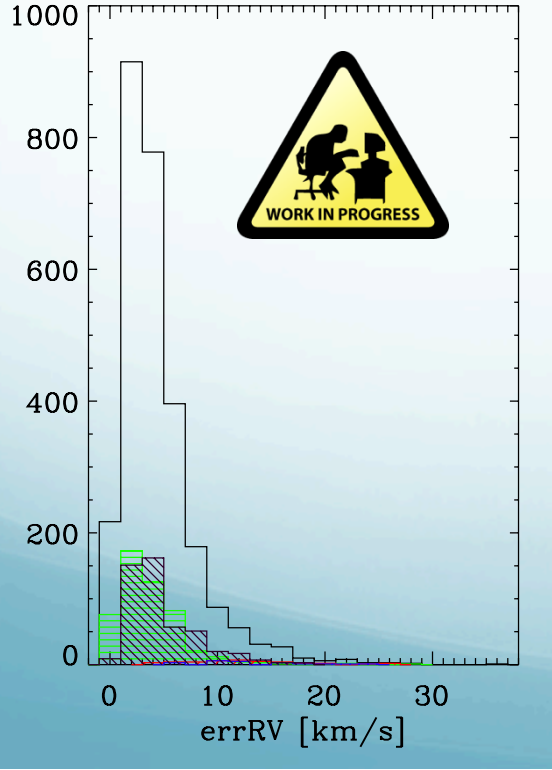


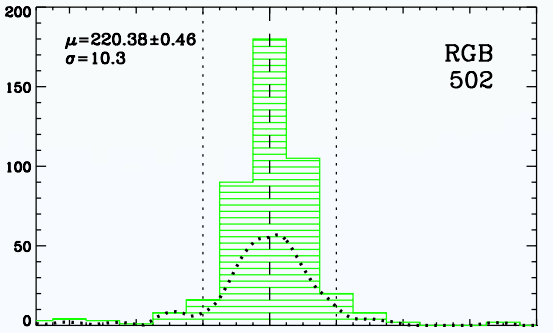
Tidal radius

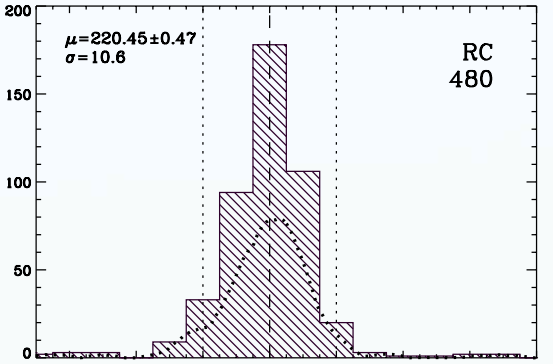
Core radius

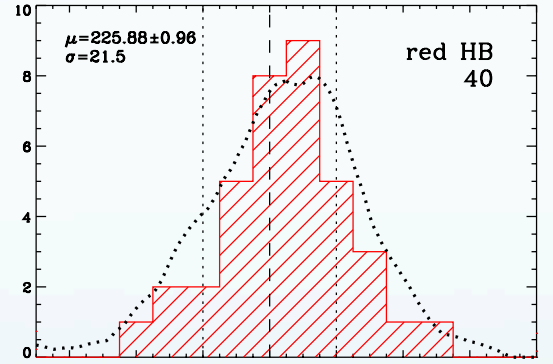
Fabrizio et al. 2014 in preparation

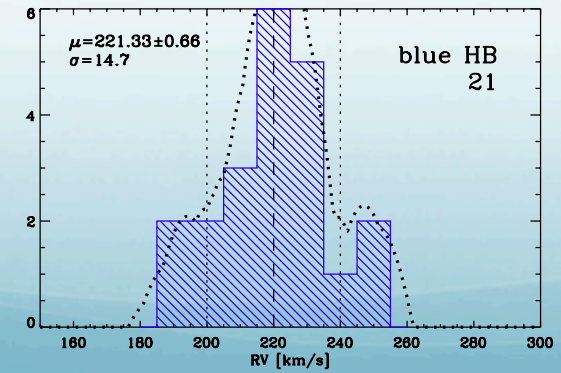












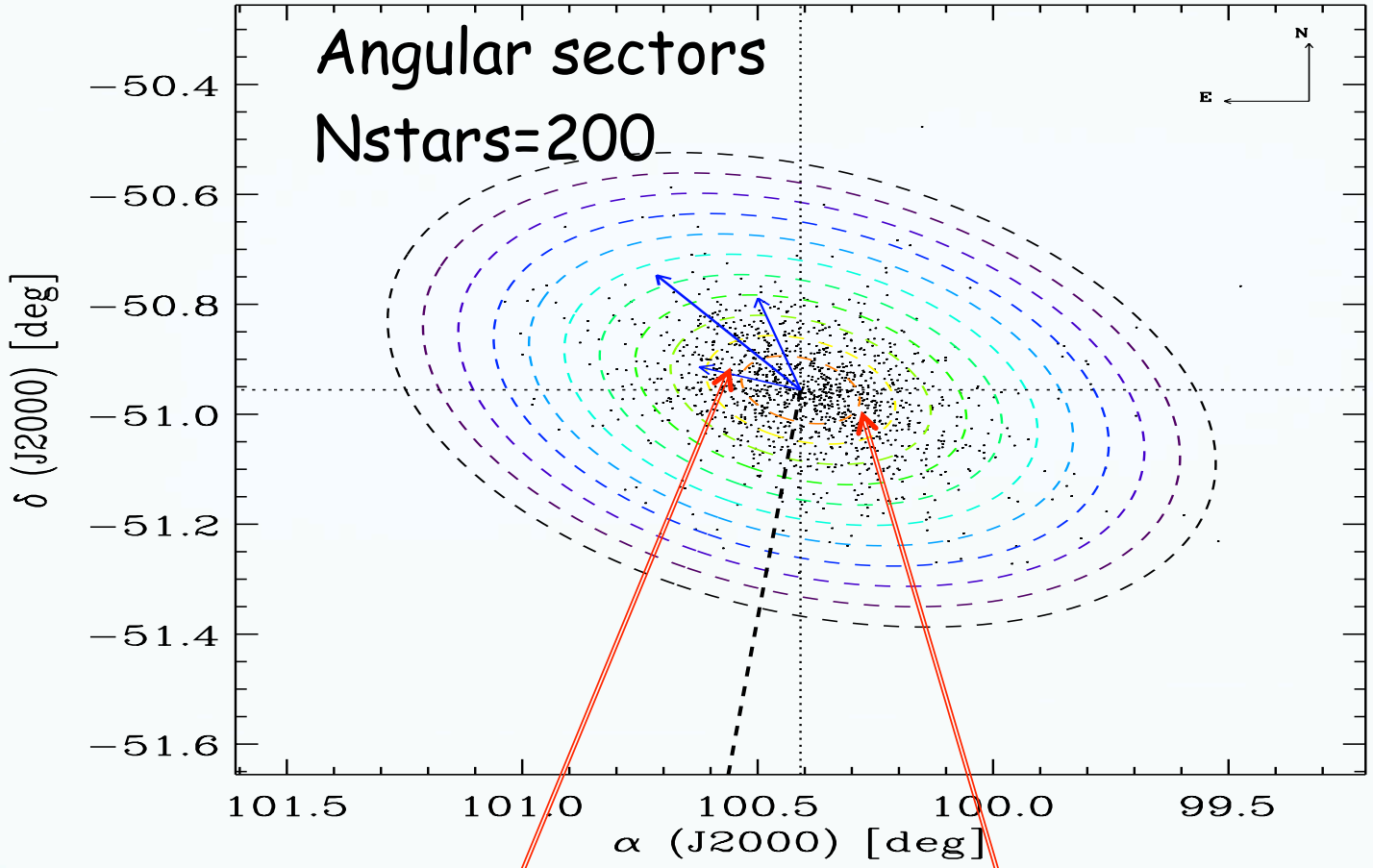
Radial Velocity distributions

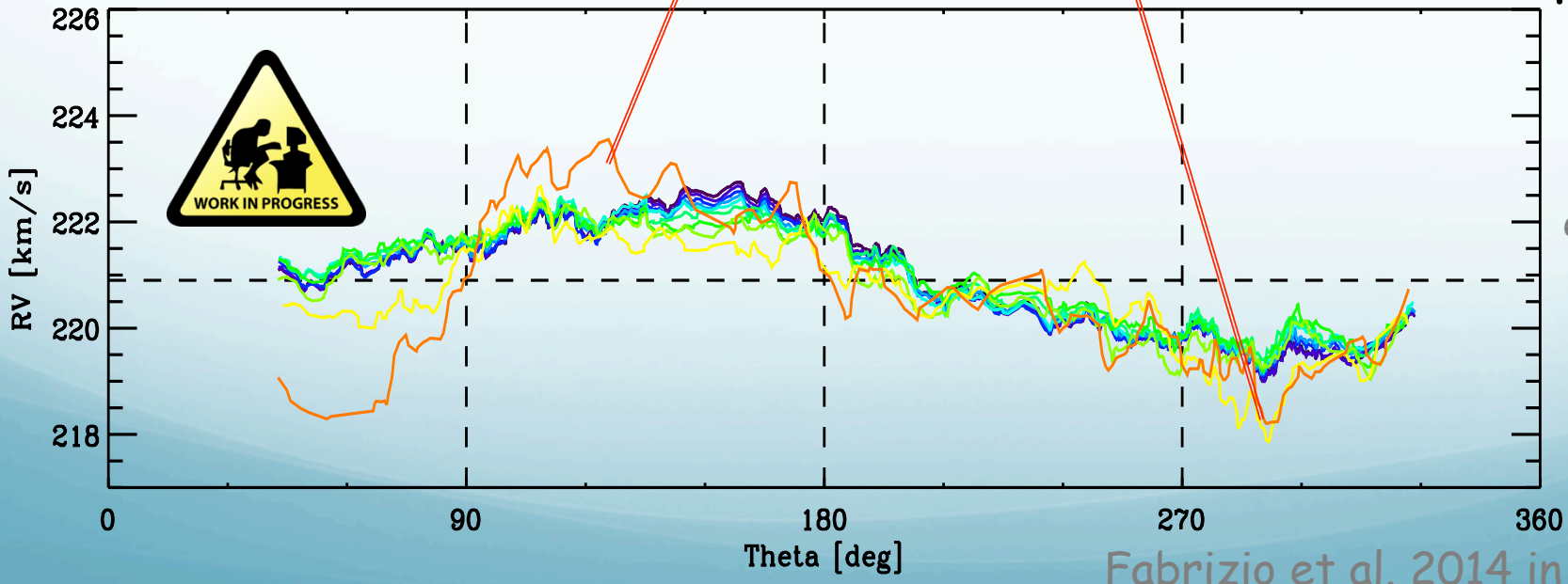
The whole sample allowed us to separate stars belonging to each evolutionary phase and to analyze their velocity distribution.

Therefore, we can study individually the kinematics of old and intermediate age population.

There is a mild evidence that the RC stars are "kinematical cooler" than the HB ones..

Fabrizio et al. 2014 in preparation





Also found in other dSphs e.g. Sculptor

Battaglia et al. 2008

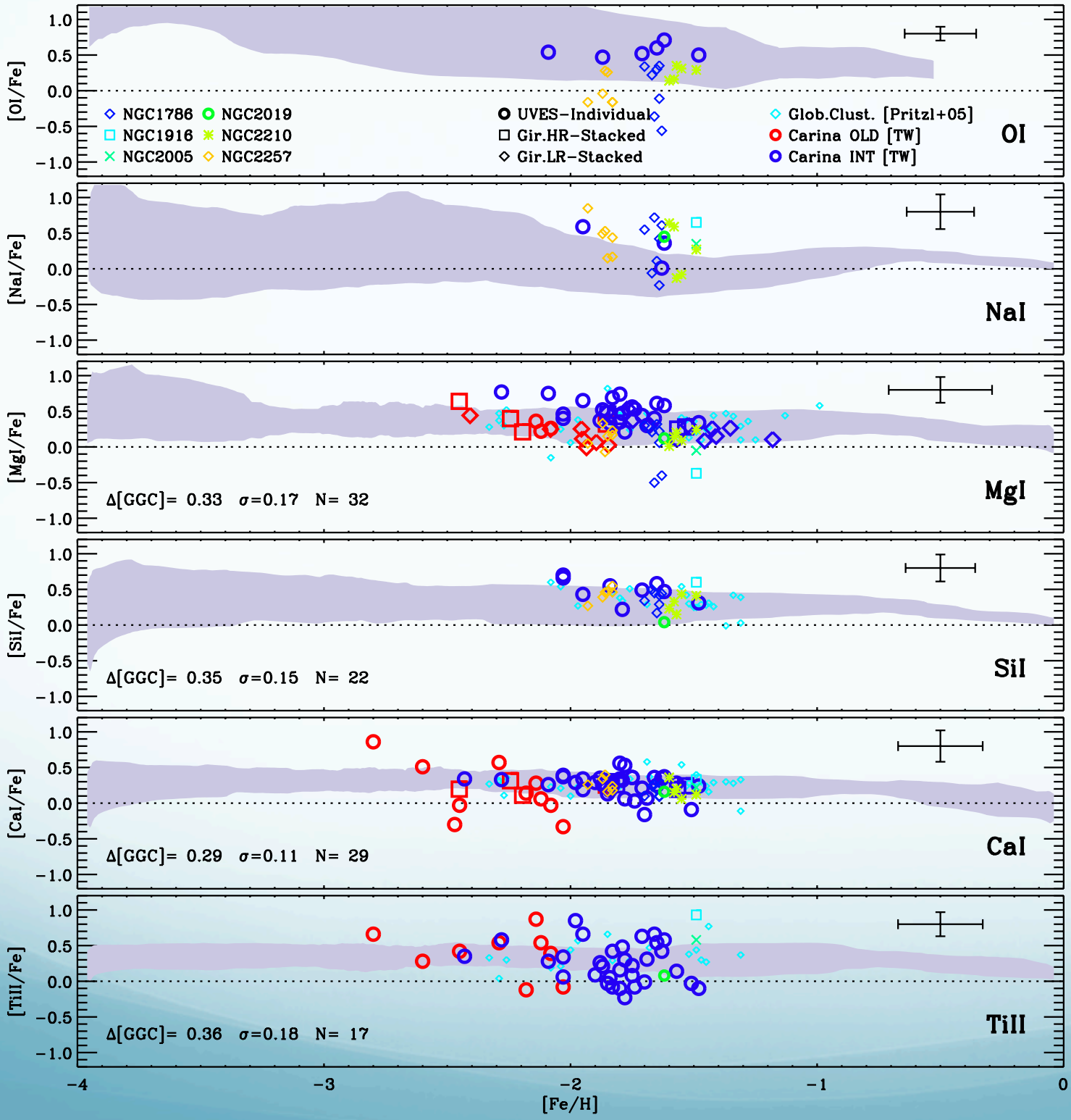
Rotation curve

↓

Cusp vs Core

e.g. Gilmore et al. 09

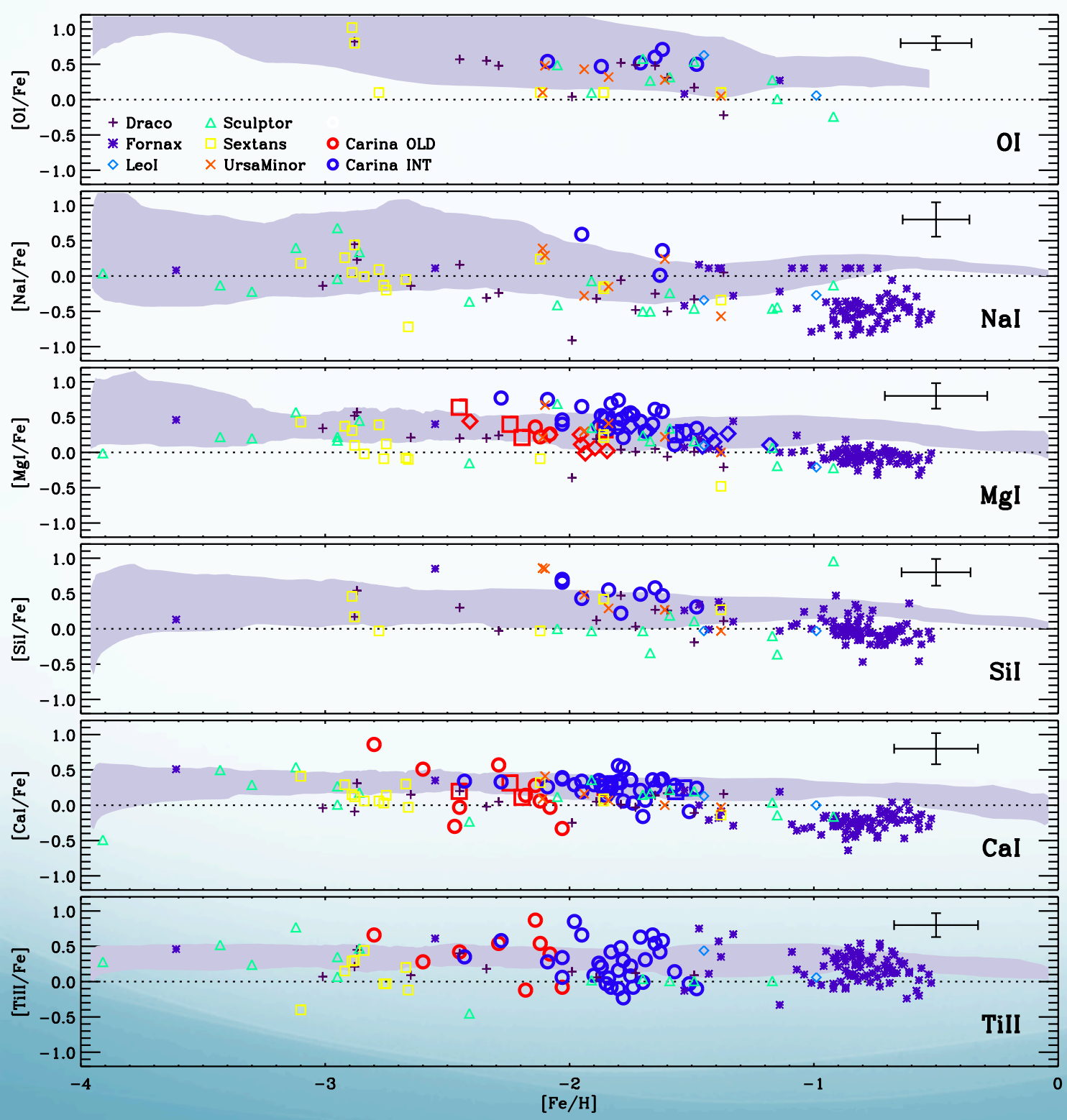
Fabrizio et al. 2014 in preparation



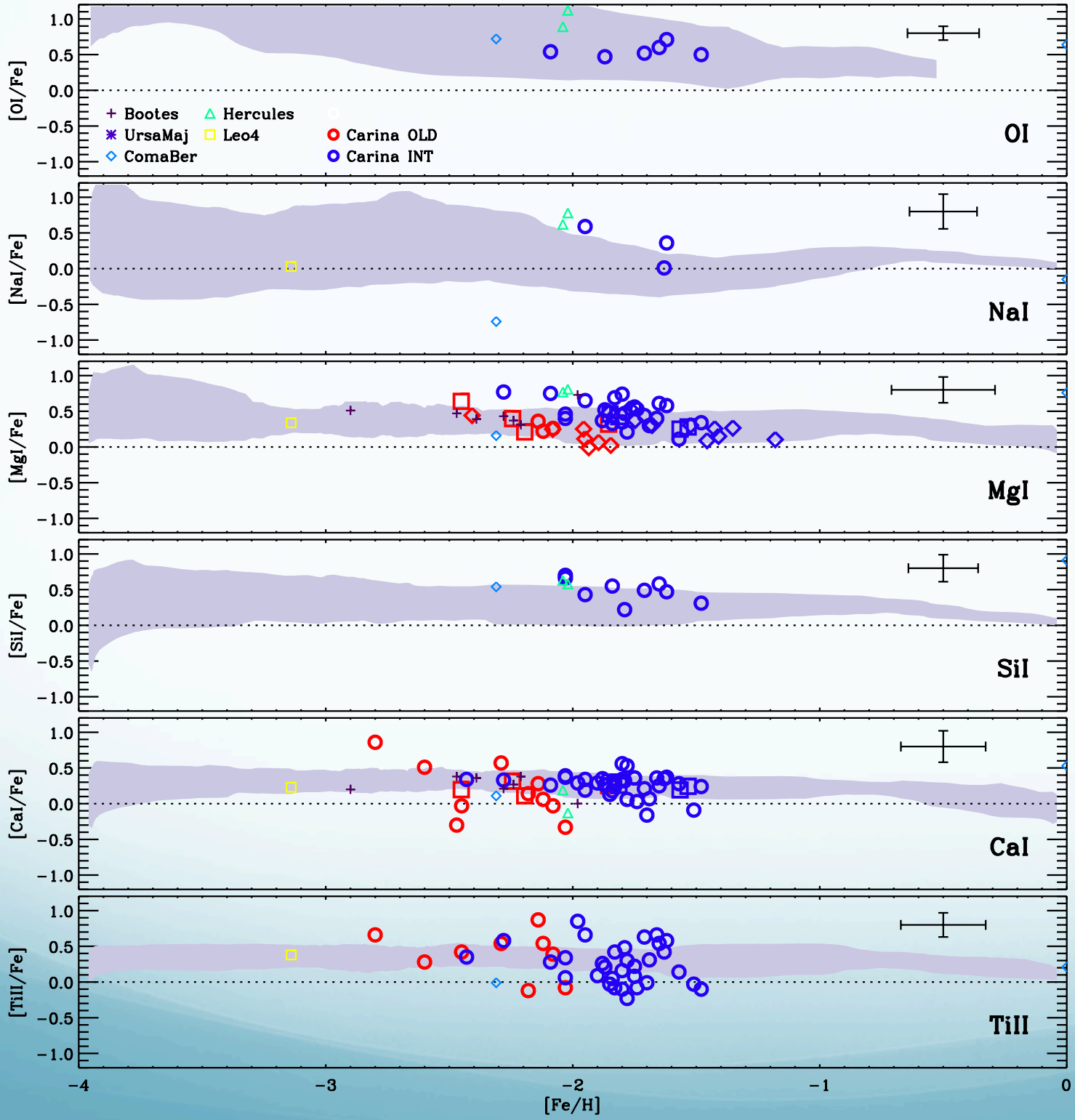
Comparison with Globular Cl. MW & LMC

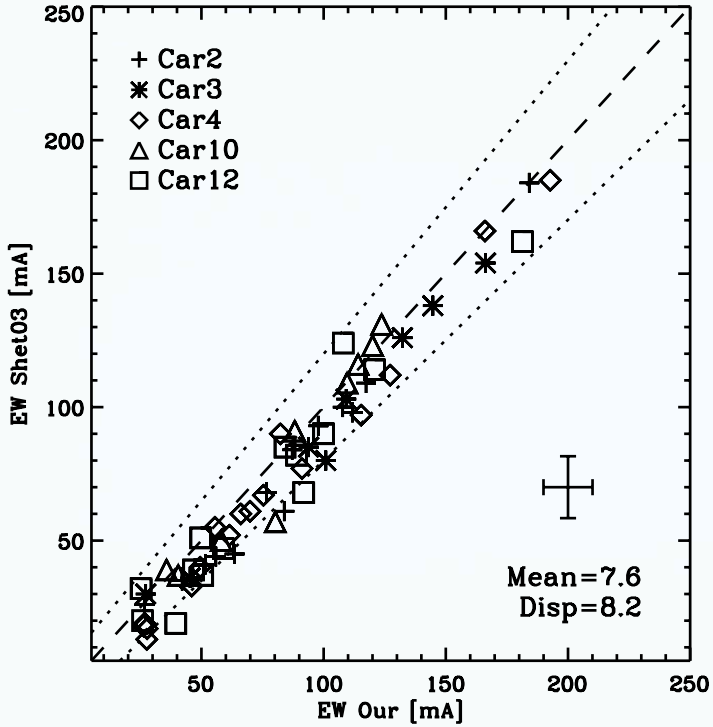
In the considerate iron range, a good agreement with α-el. abundances of GC was found

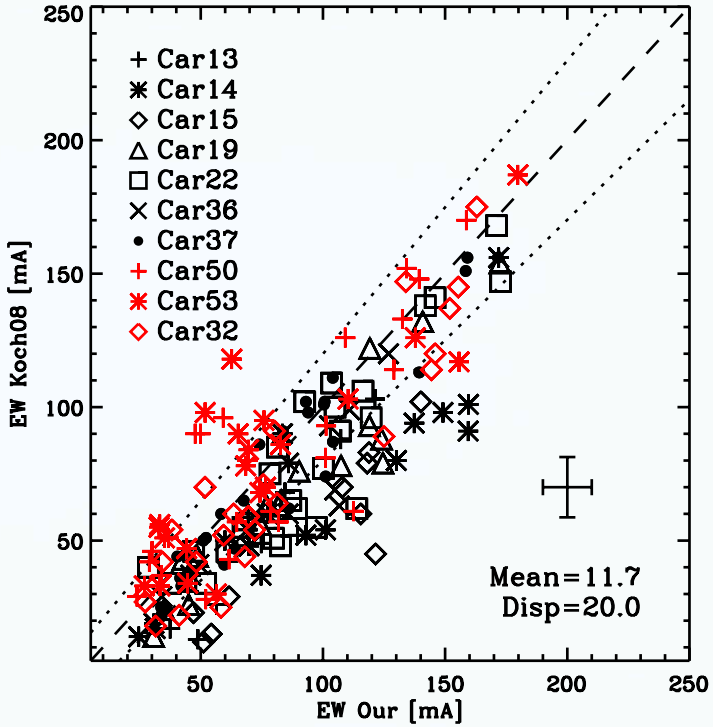
Comparison with dSphs

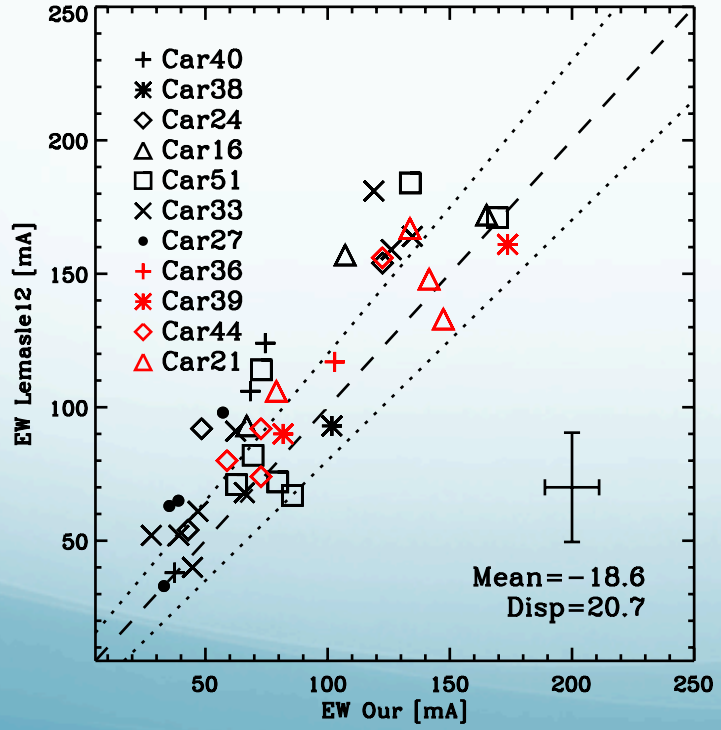


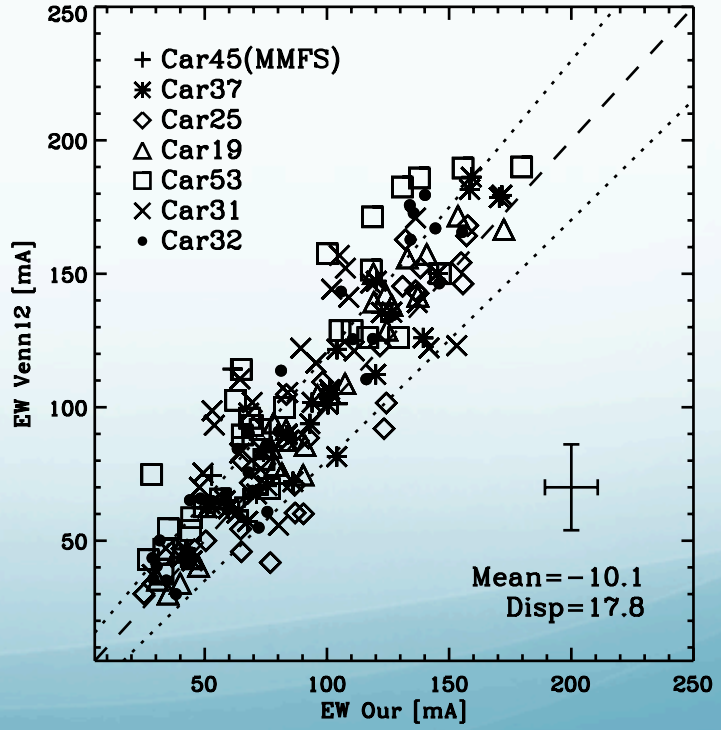
Comparison with UFDs

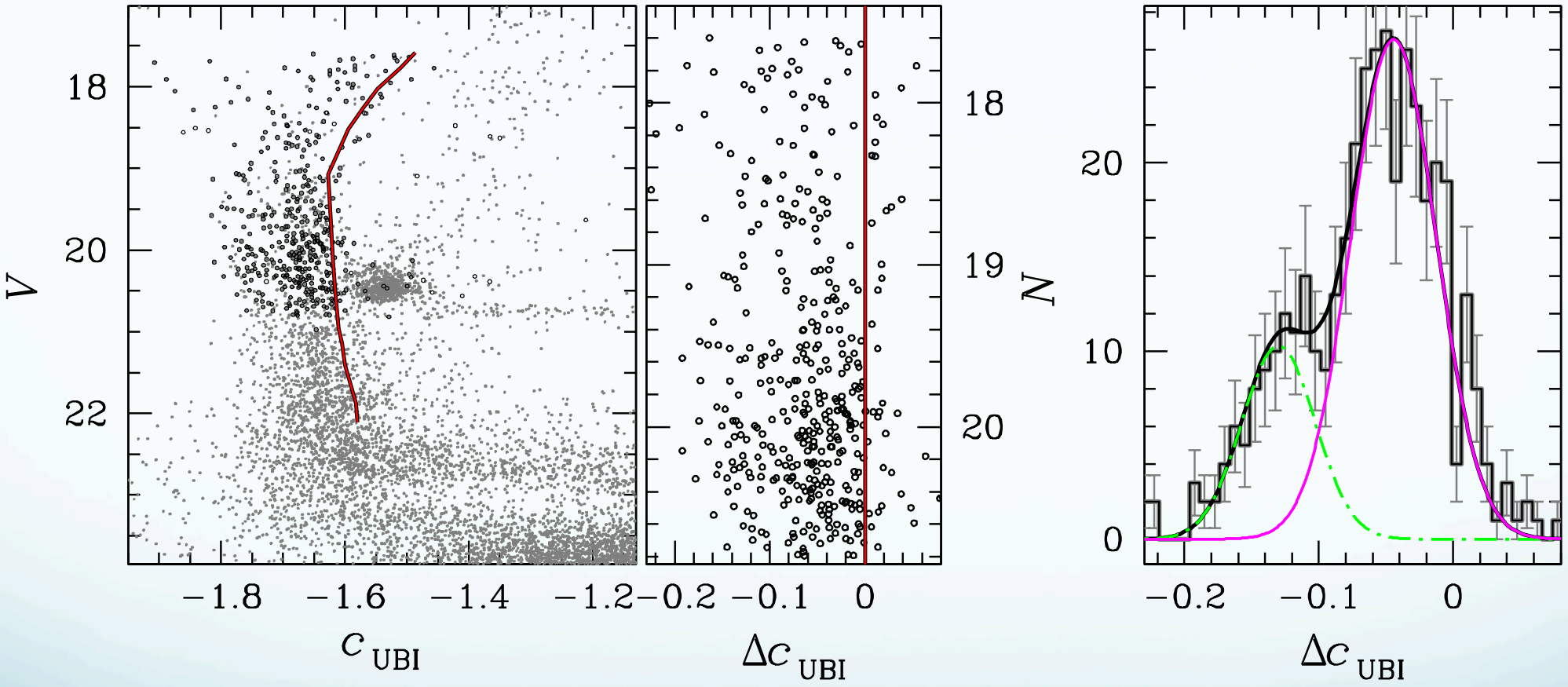



+ Car2
* Car3
◇ Car4
△ Car10
□ Car12
Mean=7.6
Disp=8.2
EW Shet03 [mA]
EW Our [mA]
50
100
150
200
250


+ Car13
* Car14
◇ Car15
△ Car19
□ Car22
× Car36
• Car37
+ Car50
* Car53
◇ Car32
Mean=11.7
Disp=20.0
EW Koch08 [mA]
EW Our [mA]
50
100
150
200
250


+ Car40
* Car38
◇ Car24
△ Car16
□ Car51
× Car33
• Car27
+ Car36
* Car39
◇ Car44
△ Car21
Mean=−18.6
Disp=20.7
EW Lemasle12 [mA]
EW Our [mA]
50
100
150
200
250


+ Car45(MMFS)
* Car37
◇ Car25
△ Car19
□ Car53
× Car31
• Car32
Mean=−10.1
Disp=17.8
EW Venn12 [mA]
EW Our [mA]
50
100
150
200
250


18
20
22
V
−1.8
−1.6
−1.4
−1.2
c UBI
18
19
20
−0.2
−0.1
0
Δc UBI
N
20
10
0
−0.2
−0.1
0
Δc UBI