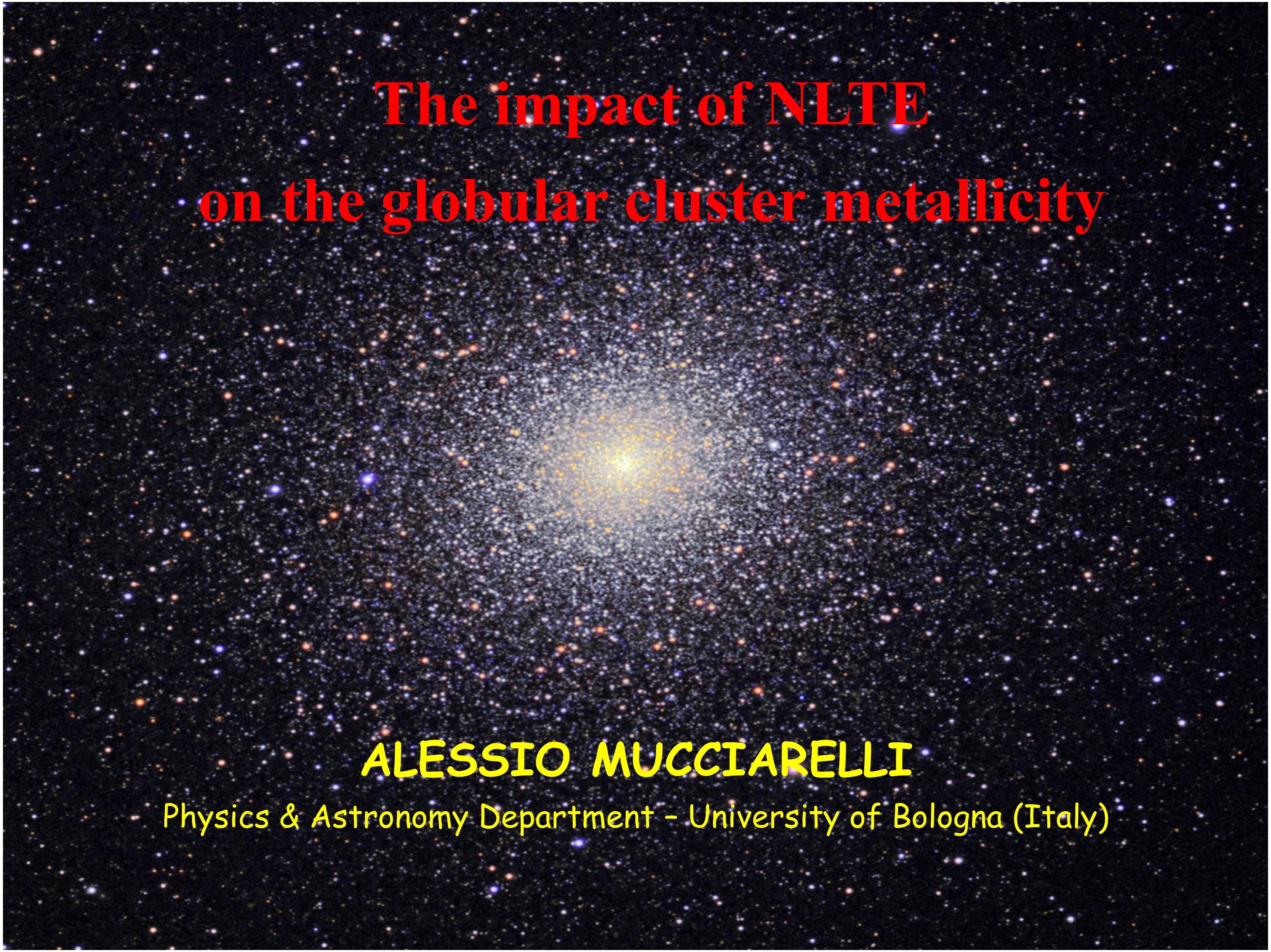


The impact of NLTE on the globular cluster metallicity

ALESSIO MUCCIARELLI

Physics & Astronomy Department – University of Bologna (Italy)

Cosmic-Lab

- 5-year project
- *Advanced Research Grant* funded by the European Research Council (ERC)
- PI: Francesco R. Ferraro (Dip. of Physics & Astronomy – Bologna University)
- AIM: **to understand the complex interplay between dynamics & stellar evolution**
- HOW: using **globular clusters** as cosmic laboratories and

  Blue Straggler Stars
  Millisecond Pulsars
  Intermediate-mass Black Holes

  } as probe-particles

Globular Clusters as Simple Stellar Populations

Simple Stellar Population (SSP)

- single stars (no binaries)
- same age (only one formation burst)
- same initial chemical composition

GCs are useful tools to study

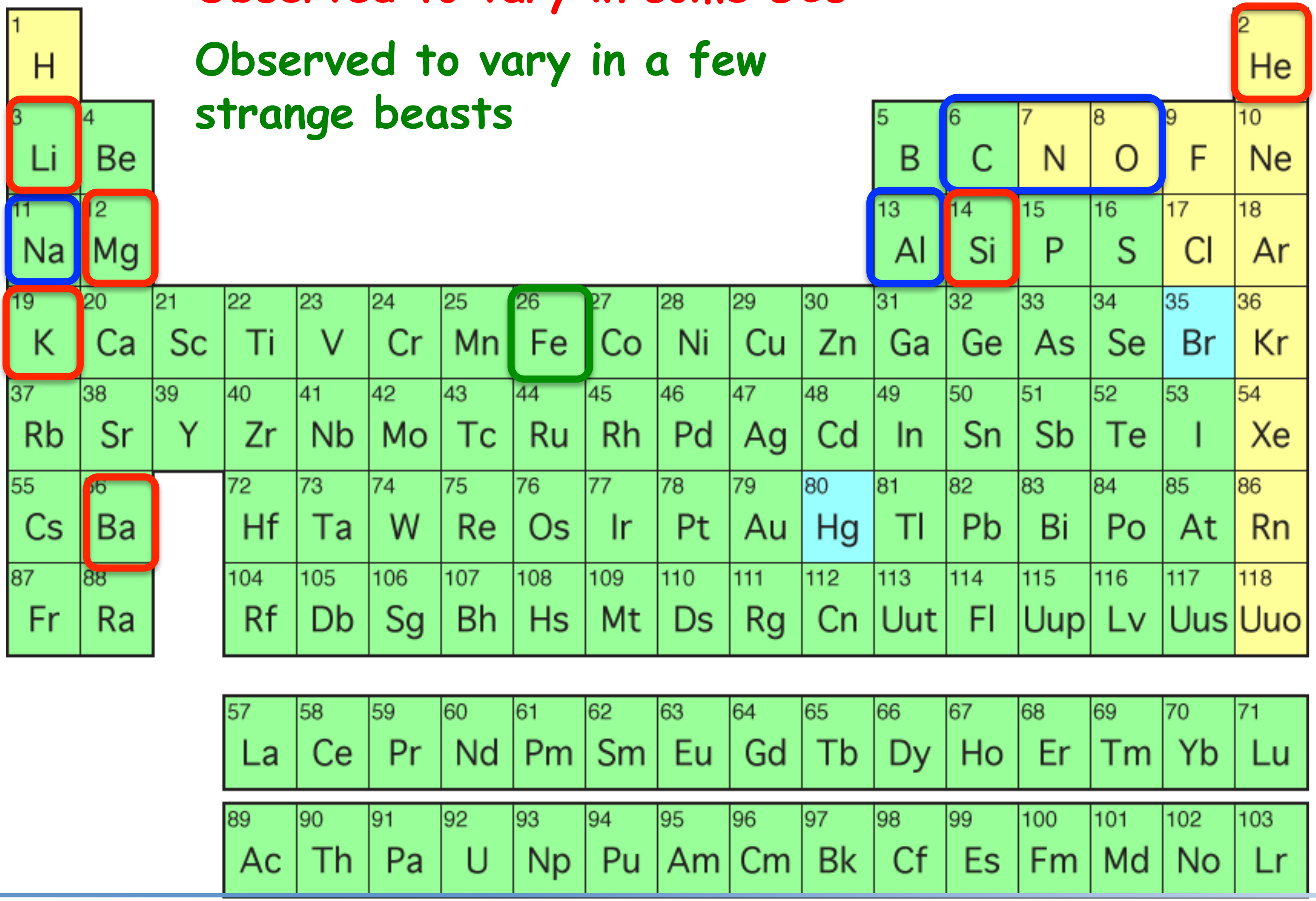
- Stellar evolution
- Chemical enrichment history of the parent galaxy
- Unresolved Stellar Populations

………..

Observed to vary in all GCs

Observed to vary in some GCs

Observed to vary in a few strange beasts



Fe (and Fe-peak elements)

GOLDEN RULE

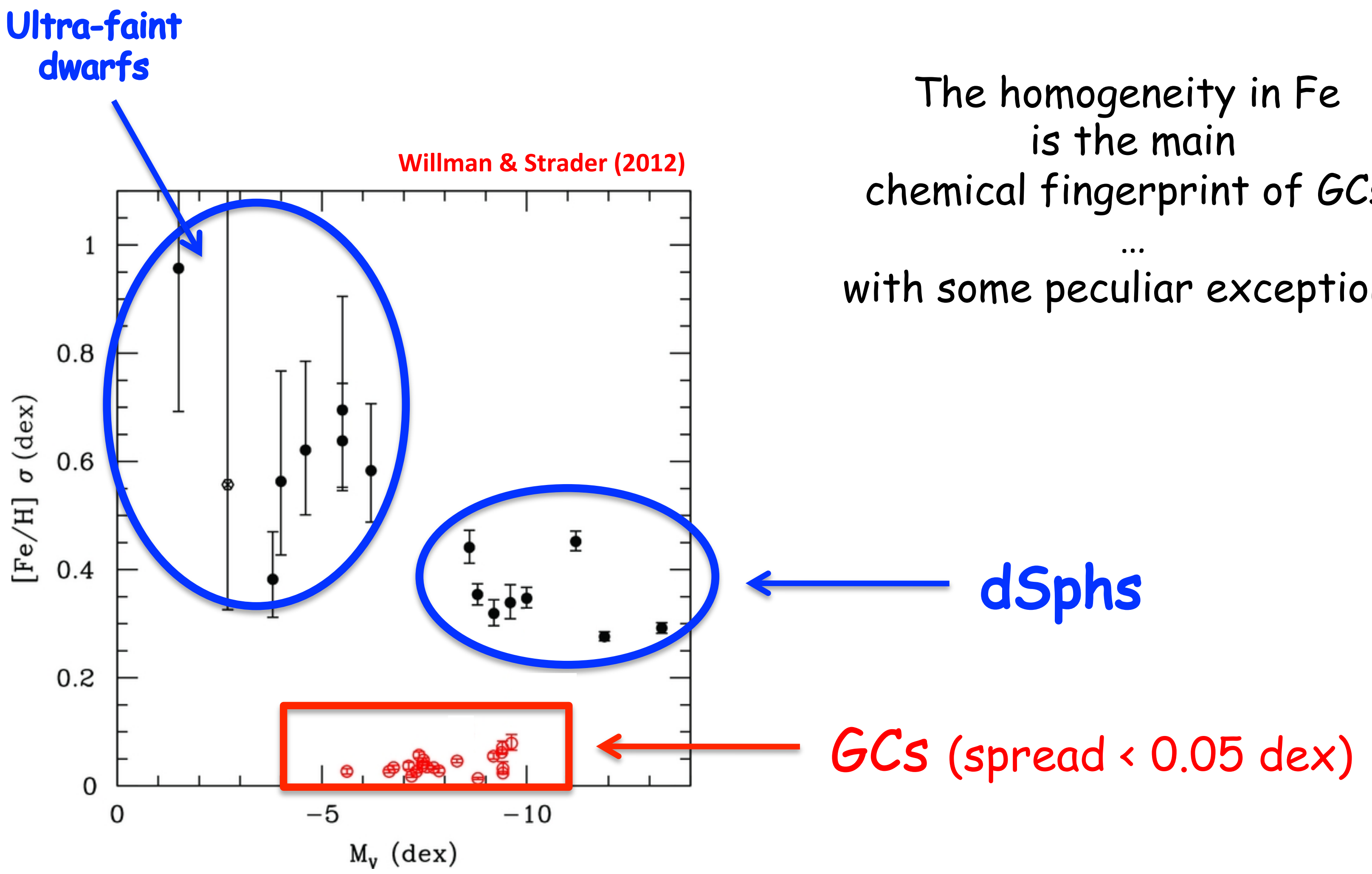
Genuine GCs are homogeneous in their Fe content
(and Fe-peak elements)

Fe produced by SN II + SN Ia

Fe spread → The system is able to retain the SNe ejecta

Genuine GCs → These systems did not retain the SNe ejecta

Fe (and Fe-peak elements)



The homogeneity in Fe
is the main
chemical fingerprint of GCs
…
with some peculiar exceptions

Strange beasts … Fe spreads !!!

- Omega Centauri
- Terzan 5
- M54

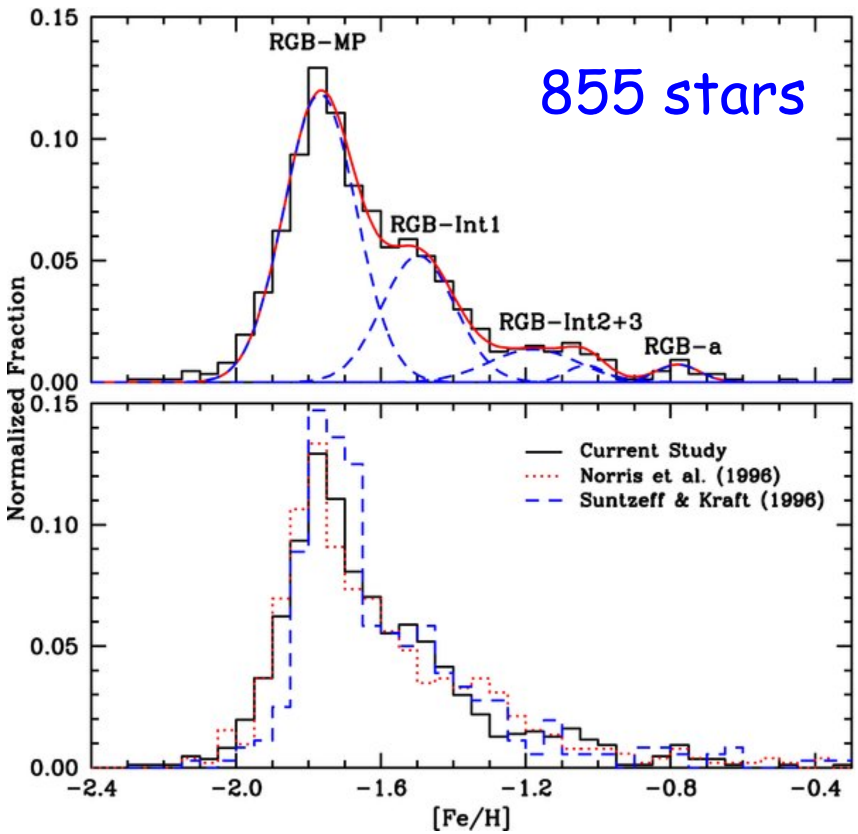
Metallicity distribution

- Large (ΔFe~1.5 dex)
- multi-modal (at least 5peaks)

It is NOT a genuine GC

(remnant of a dwarf?)

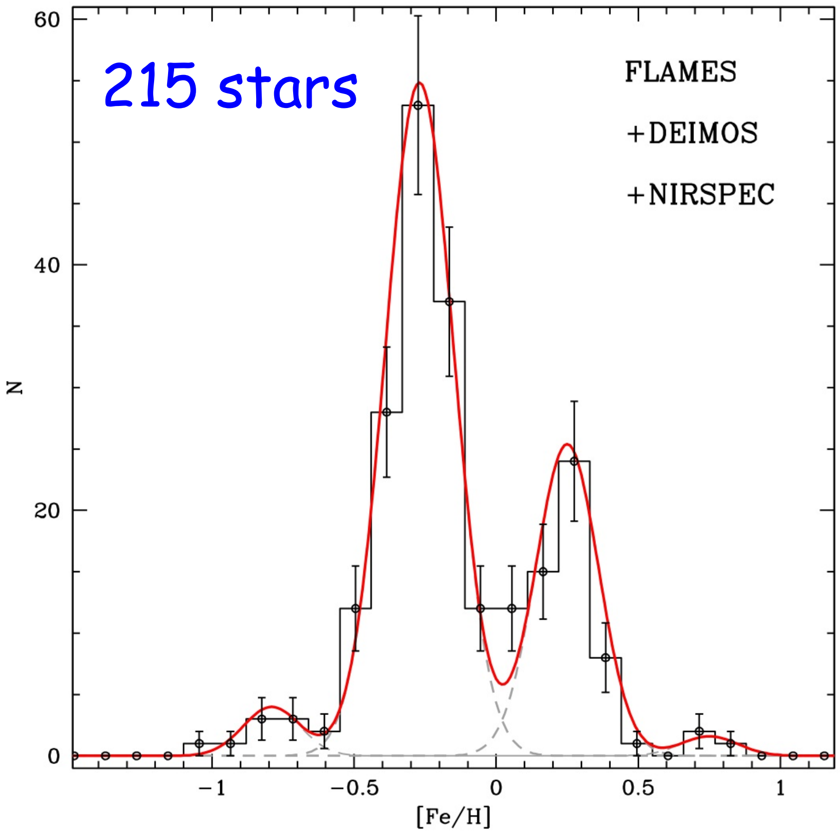
Johnson & Pilachowski (2009)



Strange beasts … Fe spreads !!!

- Omega Centauri
- Terzan 5
- M54

Massari+14



Metallicity distribution

- Large (ΔFe~1.5 dex)
- multi-modal (4 peaks)

It is NOT a genuine GC

Strange beasts … Fe spreads !!!

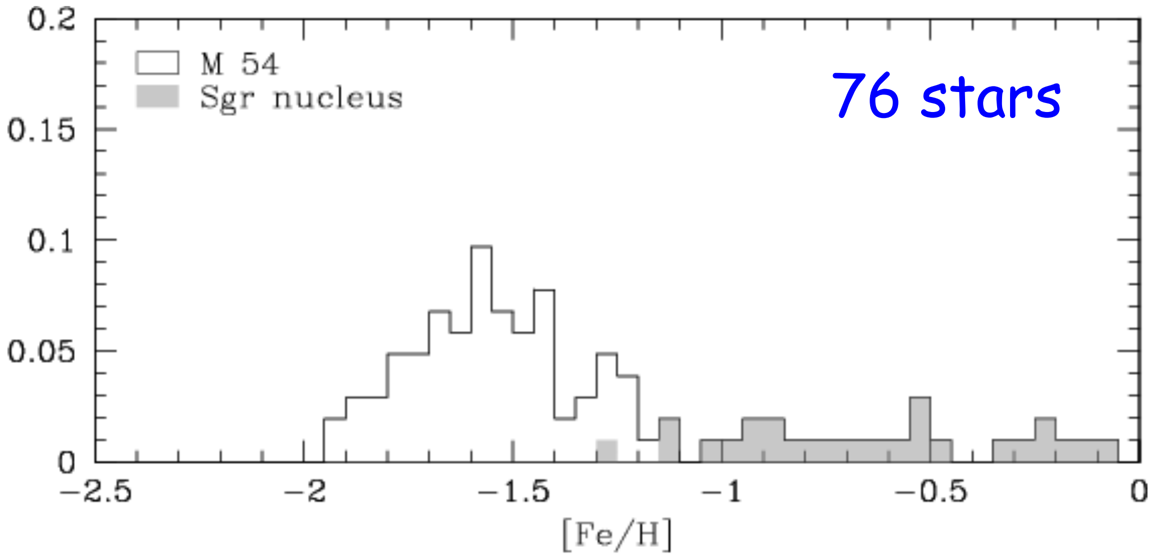
A massive GC immersed
in the nucleus of the Sgr dSph

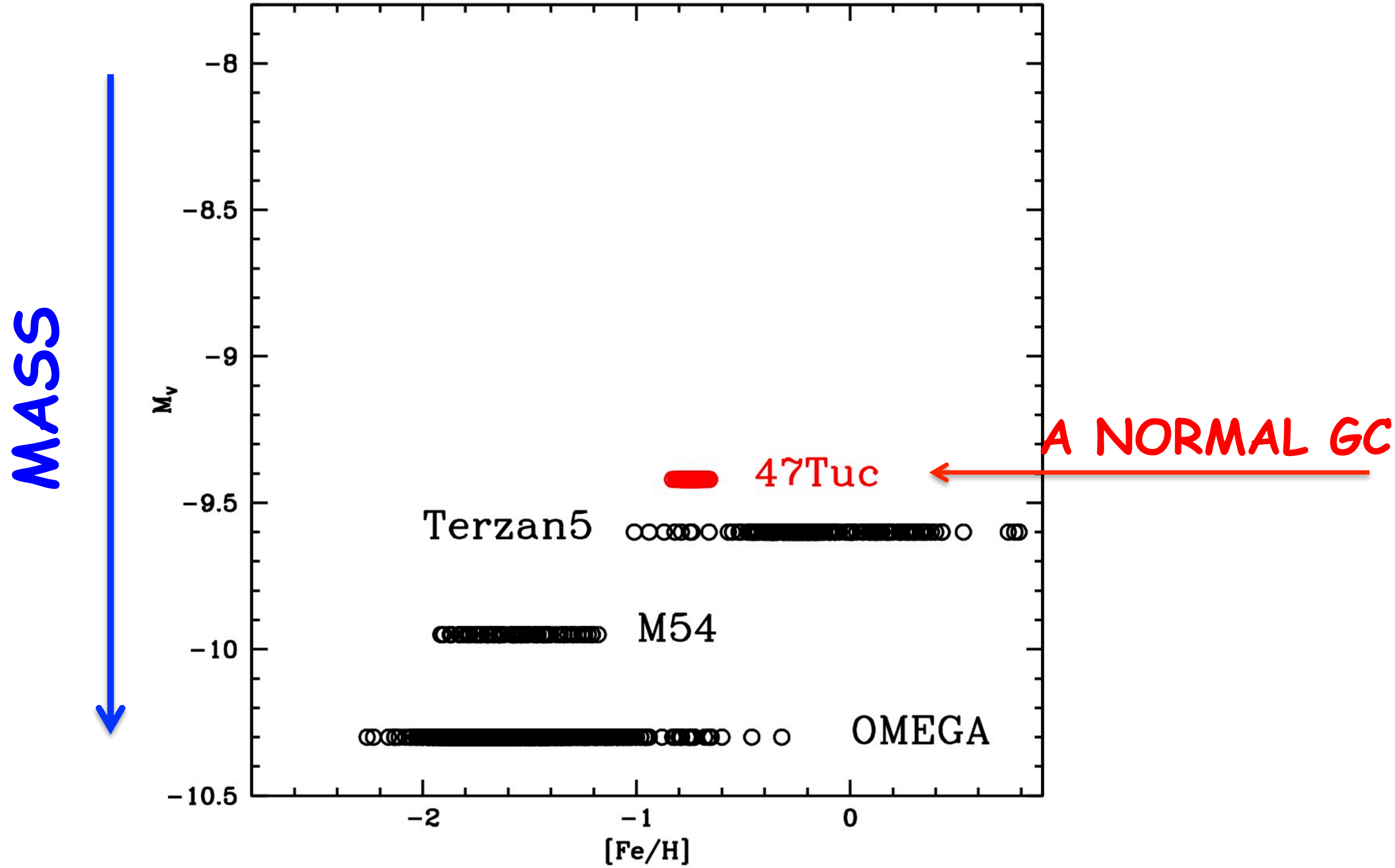
- Omega Centauri
- Terzan 5
- M54

Metallicity distribution

- Broad
- Uni-modal

Carretta+10





MASS
A NORMAL GC
47Tuc
Terzan5
M54
OMEGA
M_V
[Fe/H]
-8
-8.5
-9
-9.5
-10
-10.5
-2
-1
0

Strange beasts … Fe spreads !!!

- Omega Centauri
- Terzan 5
- M54

New GCs suspected to harbor Fe spreads

M22 (Marino+09,Marino+11)
M2 (Yong+14)
NGC3201 (Simmerer+13)
NGC1851 (Carretta+10)
NGC5286 (Marino+15)

High-res spec

… and other GCs with Fe spreads from CaT
(see Da Costa+14, Mauro+14)

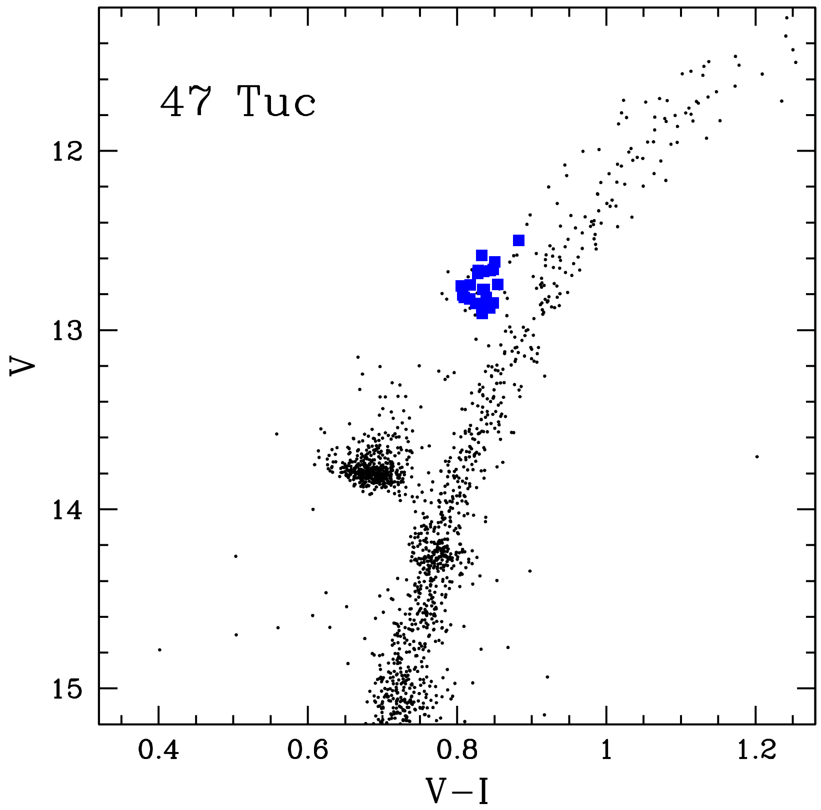
A growing number of anomalous GCs

A different formation/evolution mechanism?

AGB stars in 47 Tucanae

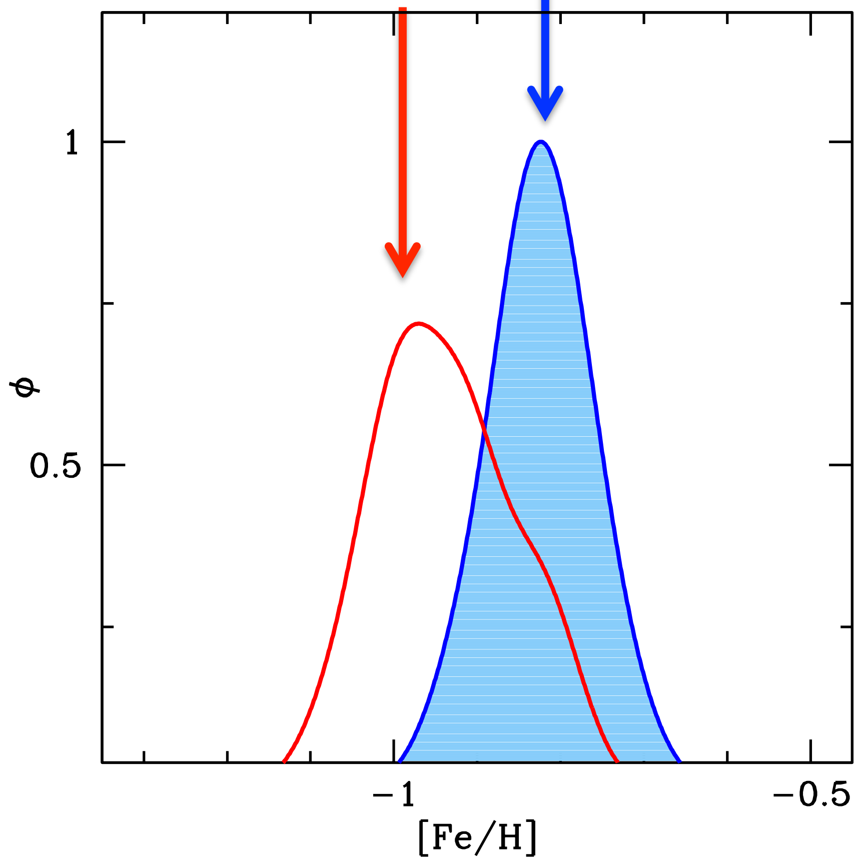
24 AGB stars observed
with FEROS@MPG/ESO
R~48000 , S/N > 70

Lapenna+14



[FeII/H]=-0.83±0.01

[FeI/H]=-0.94±0.01



Cosmic-Lab

www.cosmic-lab.eu

erc

Checks: analysis procedure

11 RGB stars observed
with FLAMES-UVES@VLT
R~45000 , S/N > 50

Homogenous analysis:
- Same linelist
- Same model atmospheres
- Same method to derive T_{eff}, logg…

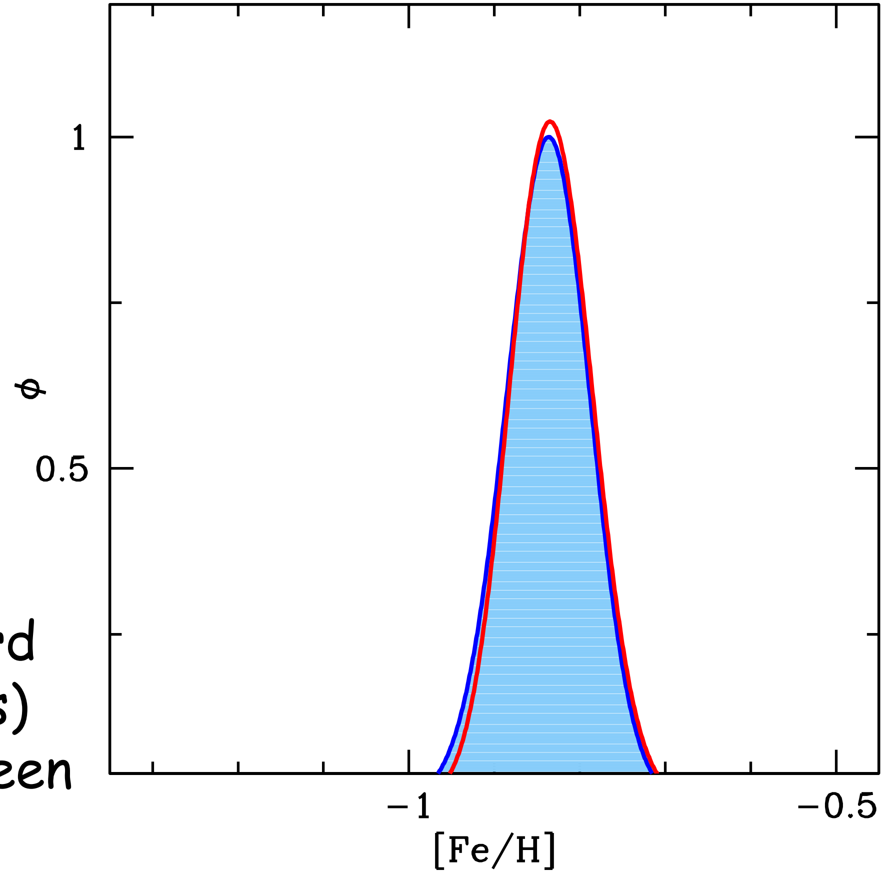
A problem with FEROS?

NO !!!

The analysis of 104Tau (a RV standard star observed during the same nights) provides compatible abundance between FeI and FeII

[FeI/H]=-0.83±0.01

[FeII/H]=-0.84±0.01



Checks: analysis procedure

Two standard calibrators:
Arcturus + Sun
(well known atmospheric parameters)

Arcturus [FeI/H]=-0.56±0.01
[FeII/H]=-0.57±0.01

Sun A(FeI) = 7.49±0.01
A(FeII) = 7.50±0.02

The discrepancy between FeI and FeII
in the AGB of 47Tuc
cannot be due to the adopted linelist

Checks: atmospheric parameters

- ✓ Both spectroscopic and photometric T_{eff} provide the same results

- ✓ To reconcile FeI and FeII we need to decrease logg (FeII is sensitive to logg, at variance with FeI), but …

  - [FeI/H] ~ [FeII/H] ~ -1.0 dex
    too low abundance, large difference with the RGB stars

  - the spectroscopic logg imply low stellar masses, ~0.4 M_{SUN}
    (too low mass for a GC AGB star, ~0.7 M_{SUN} for 47Tuc)

No realistic sets of atmospheric parameters able to reconcile FeI and FeII in the AGB stars, matching the Fe of RGB stars

The discrepancy between FeI and FeII in AGB stars cannot be explained with uncertainties/errors in the adopted analysis procedure

"...when you have eliminated all which is impossible, then whatever remains, however improbable, must be the ***truth****"*

Sherlock Holmes

A possible explaination

Departure from Local Thermodynamical Equilibrium (LTE) assumptions

In NLTE:
neutral lines (Fe I) are affected
(lower abundance when we use LTE calculations)
single ionized lines (Fe II) unaltered

Two remarks:
(1) Fe II lines are the most reliable indicators of Fe abundance
(2) Spectroscopic logg can be biased :
we impose [Fe II/ H] ~[Fe I /H]

The best way to derive the Fe abundance

Photometric gravities
+
Fe II lines

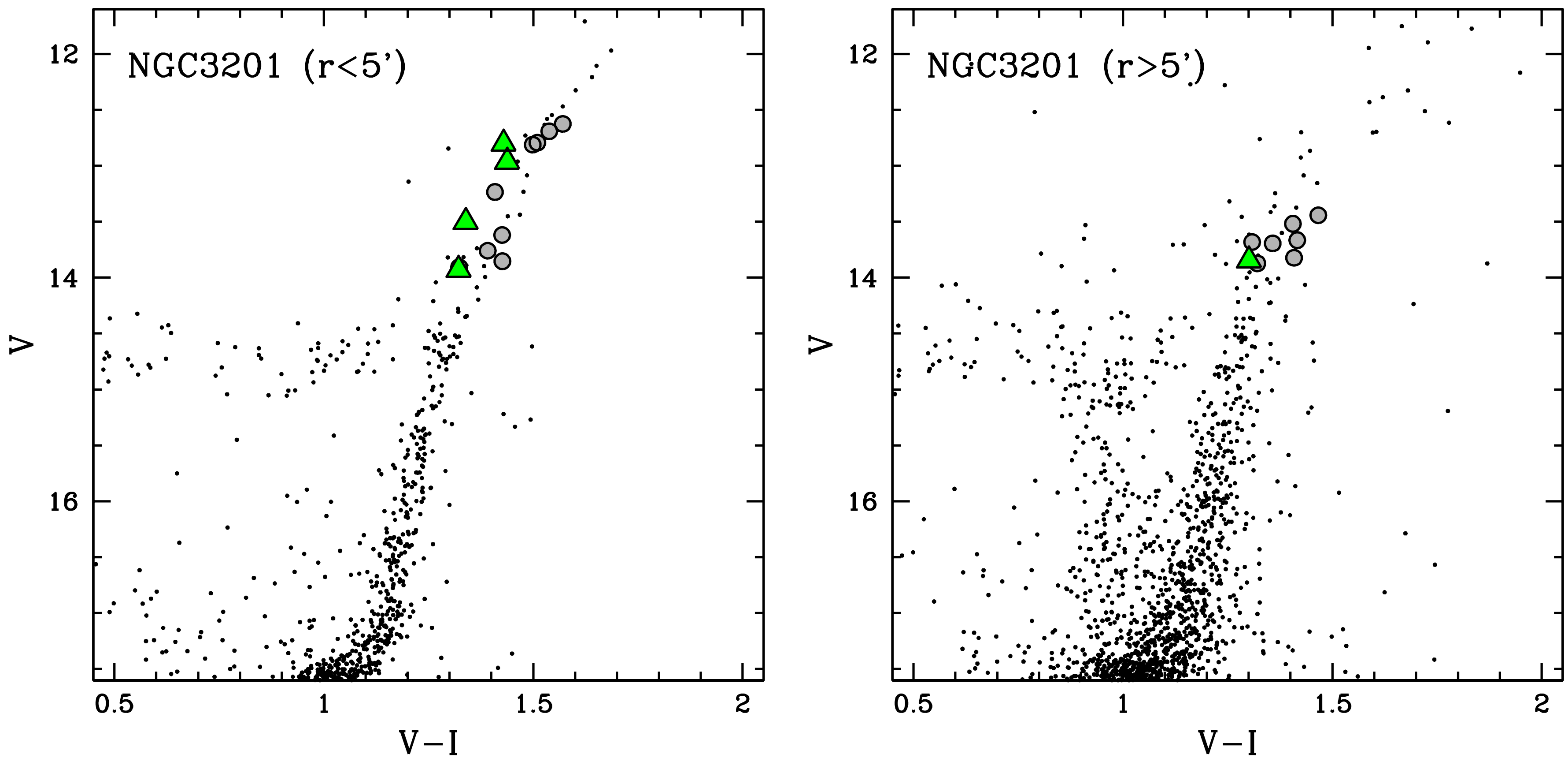
But … you need high-resolution, wide coverage spectra

In UVES & FEROS spectra 100-150 FeI lines vs 15-20 FeII lines

WARNING !!!
Several works use the spectroscopic gravities,
including some clusters with Fe spread

The case of NGC3201

Simmerer+13: analysis of 21 giant stars (FLAMES-UVES)
A 0.4 dex wide metallicity distribution
(Analysis based on spectroscopic logg)



Spectroscopic logg

[Fe I /H] = -1.46 (σ=0.10)

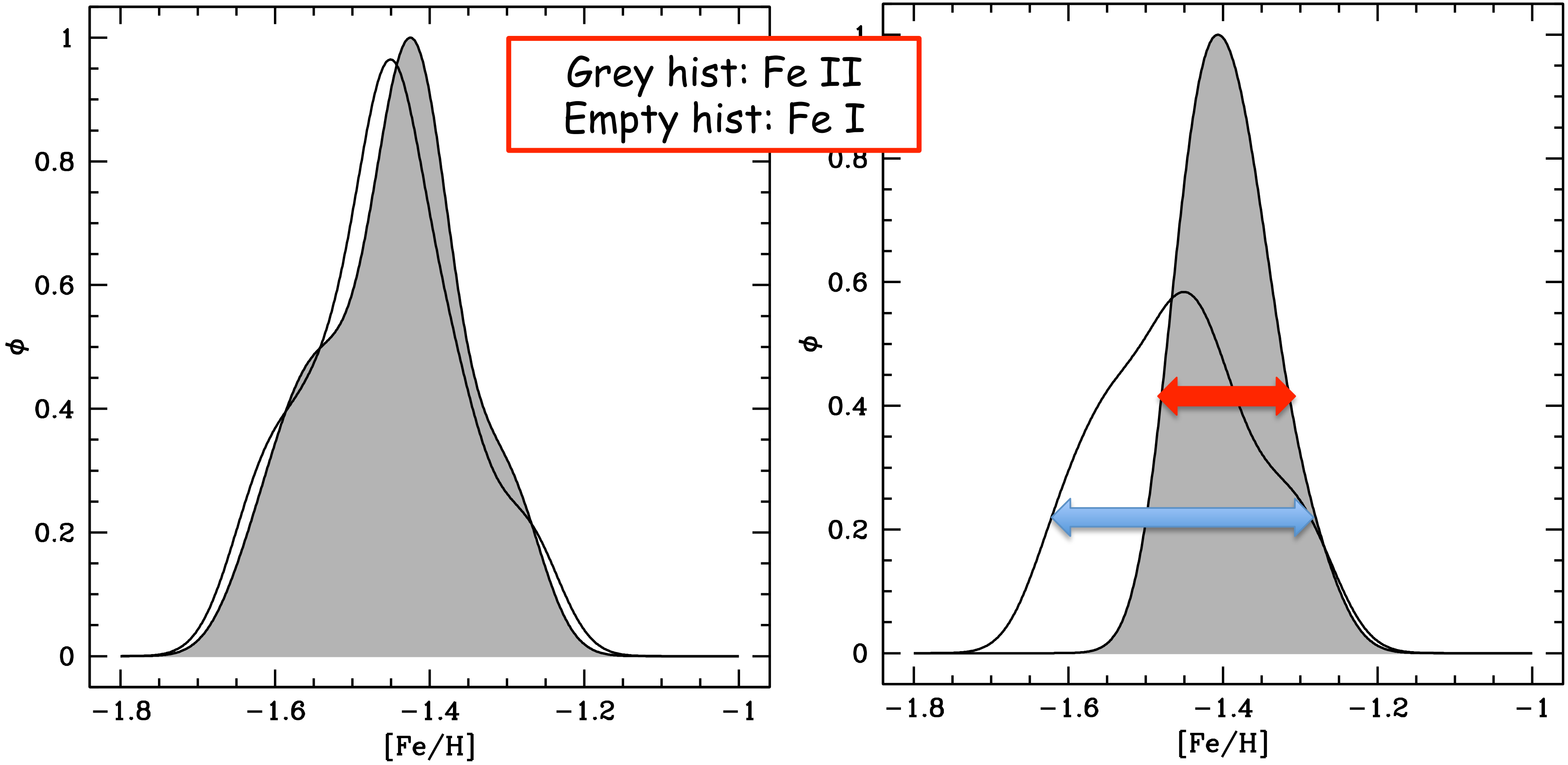
INTRINSIC FE SPREAD !!!

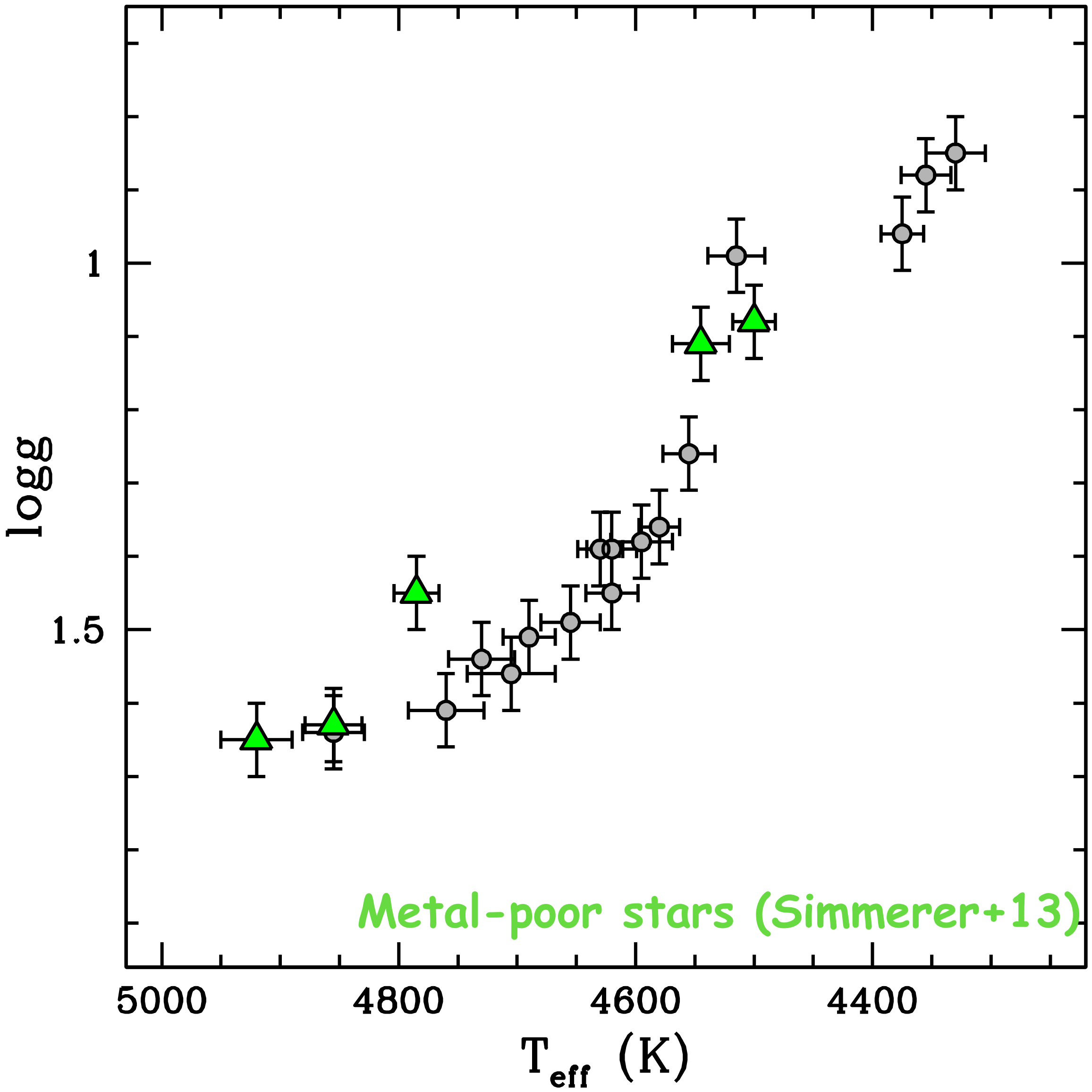
Photometric logg

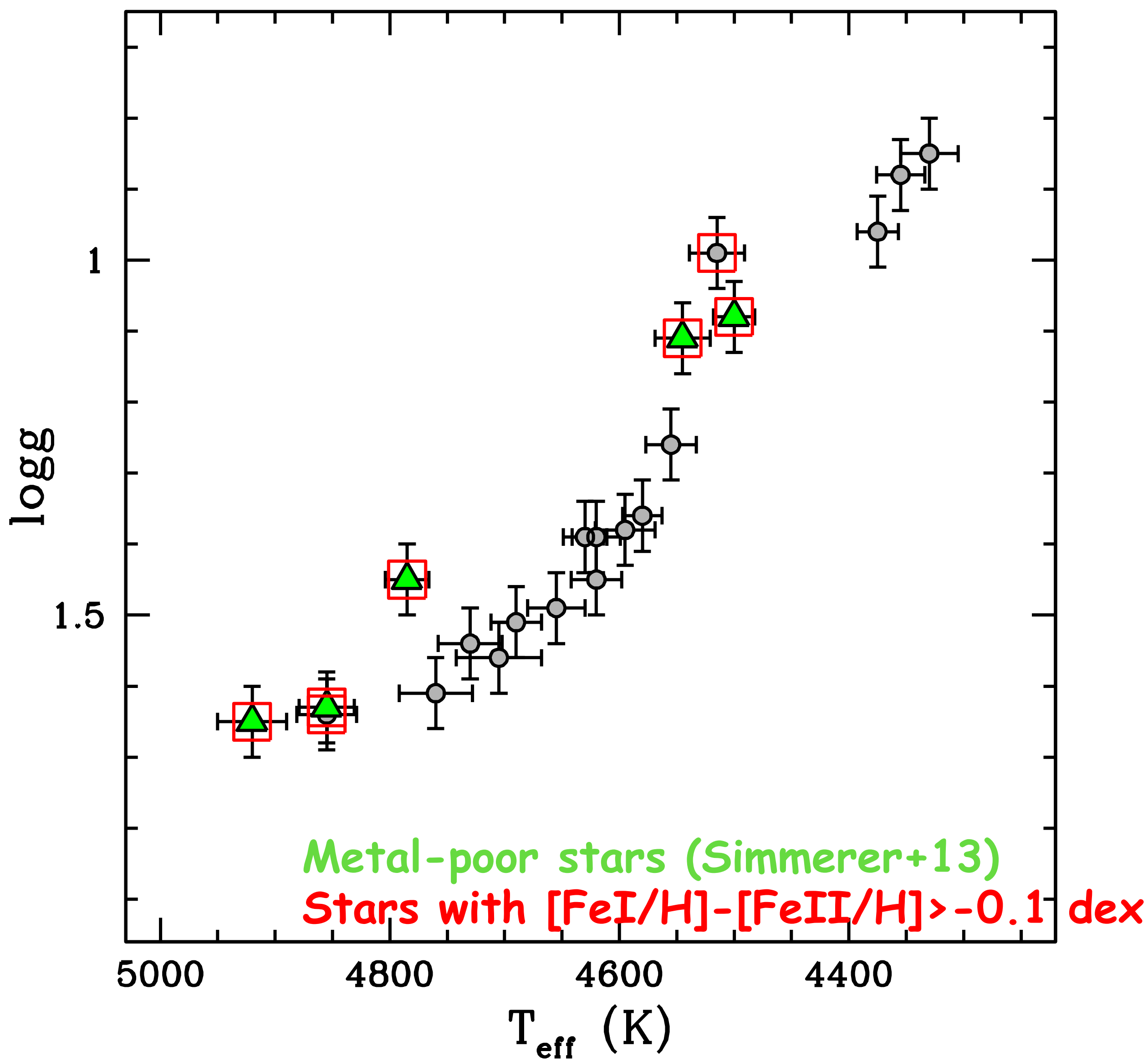
[Fe I /H] = -1.46 (σ=0.10)
[Fe II /H] = -1.40 (σ=0.05)

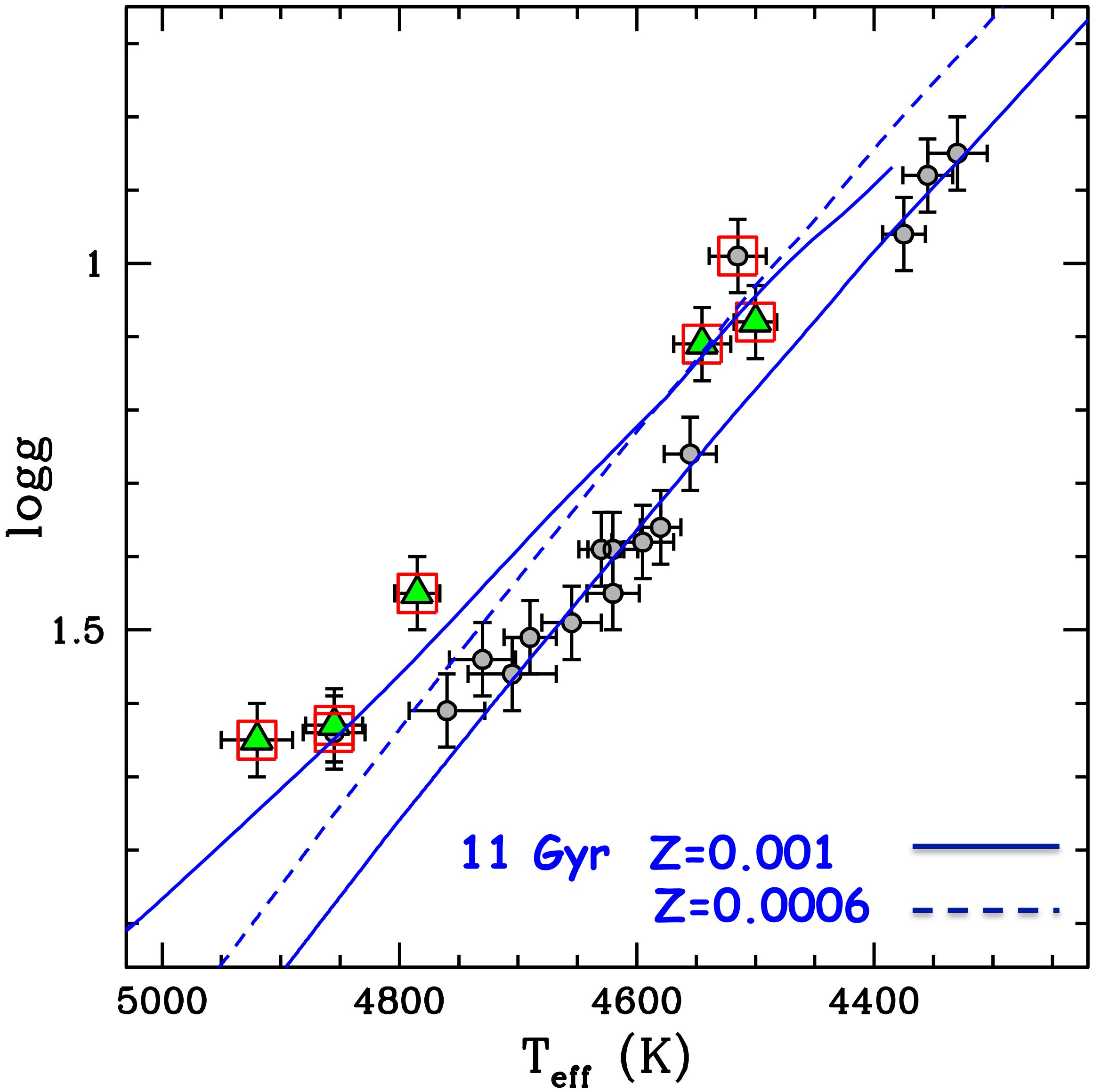
Fe II : NO intrinsic Fe spread !!!

Mucciarelli+15

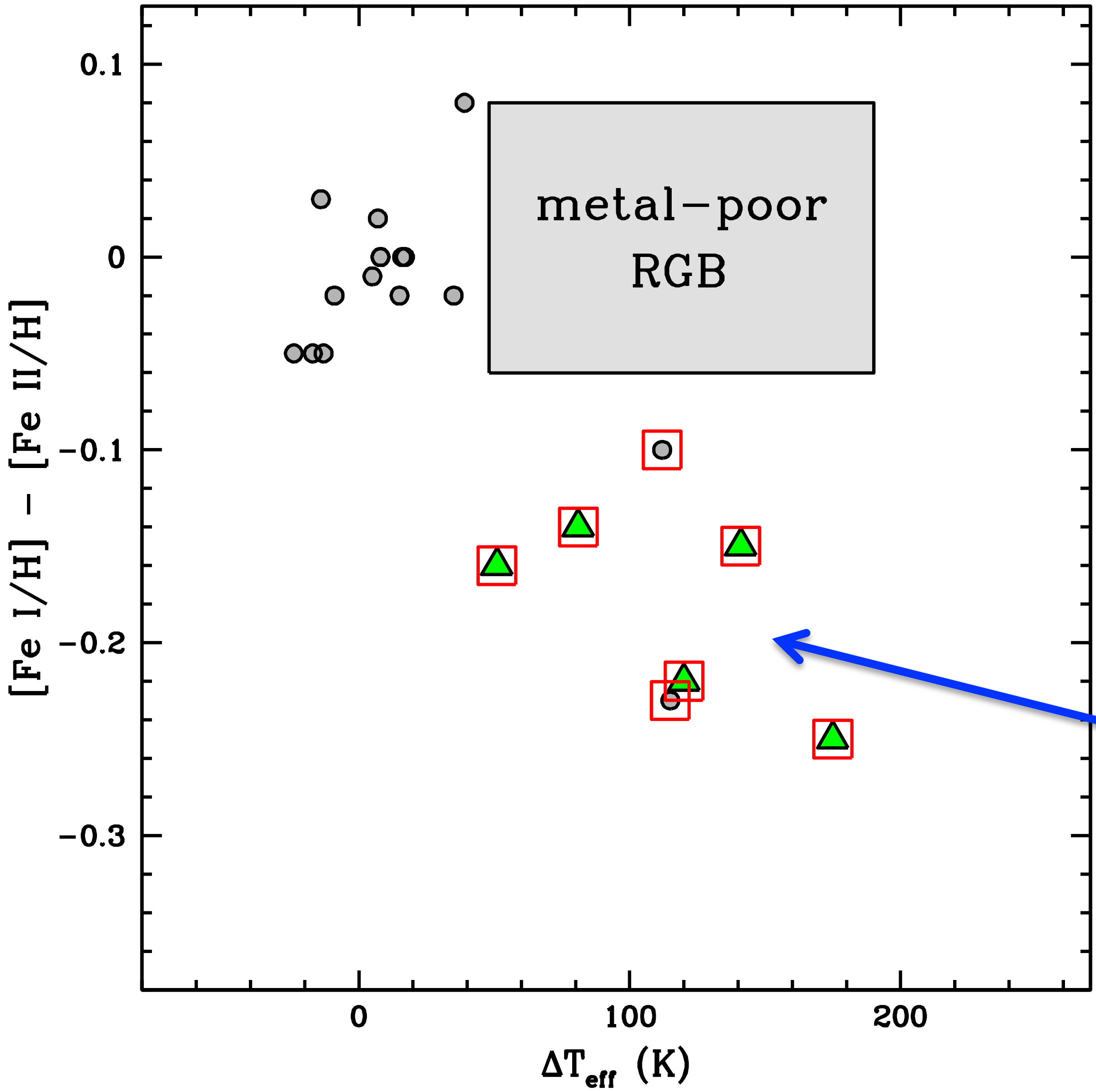


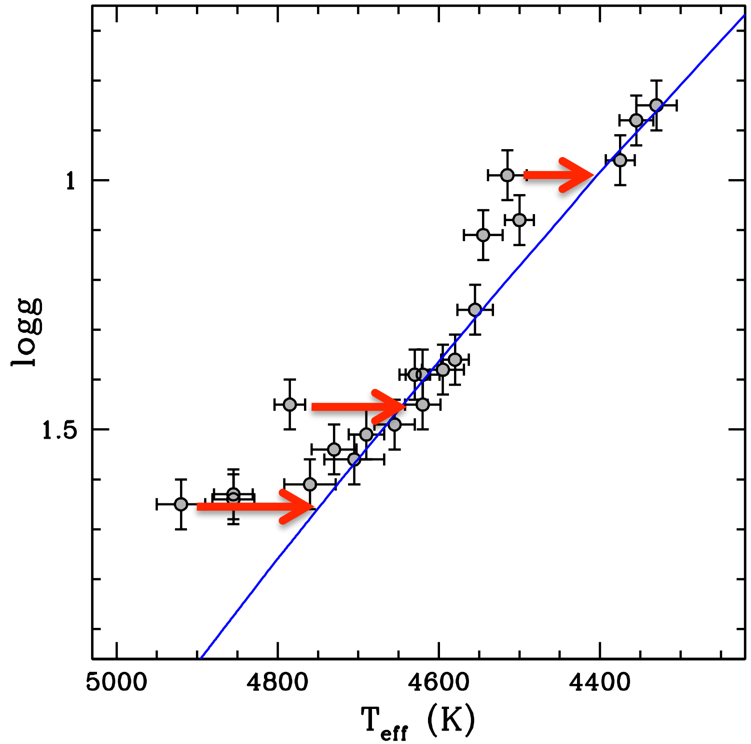

Metal-poor stars (Simmerer+13)
logg
1
1.5
5000
4800
4600
4400
T_{eff} (K)


logg
1
1.5
5000
4800
4600
4400
Teff (K)
Metal-poor stars (Simmerer+13)
Stars with [FeI/H]-[FeII/H]>-0.1 dex

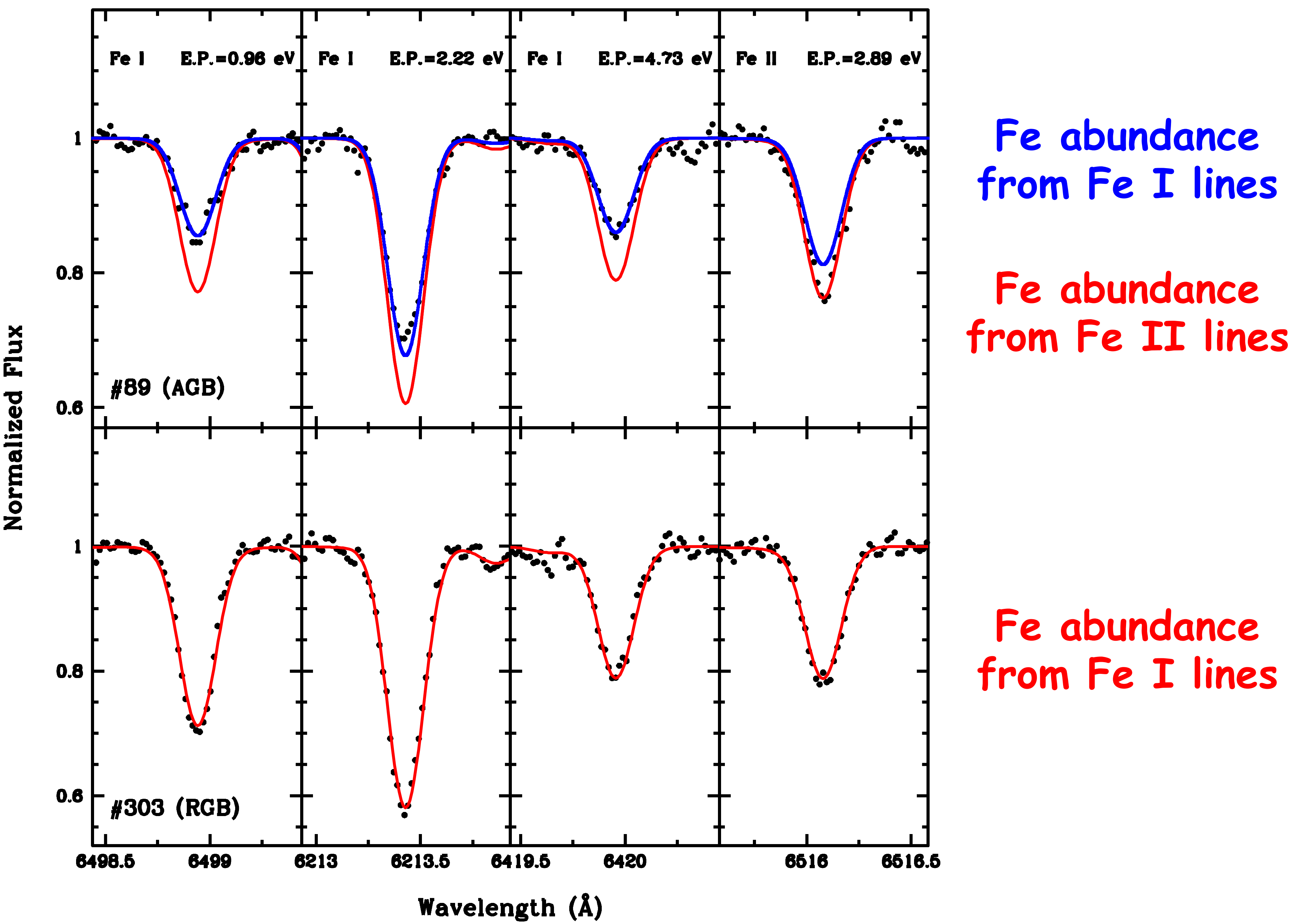


logg
1
1.5
5000
4800
4600
4400
T eff (K)
11 Gyr Z=0.001
Z=0.0006

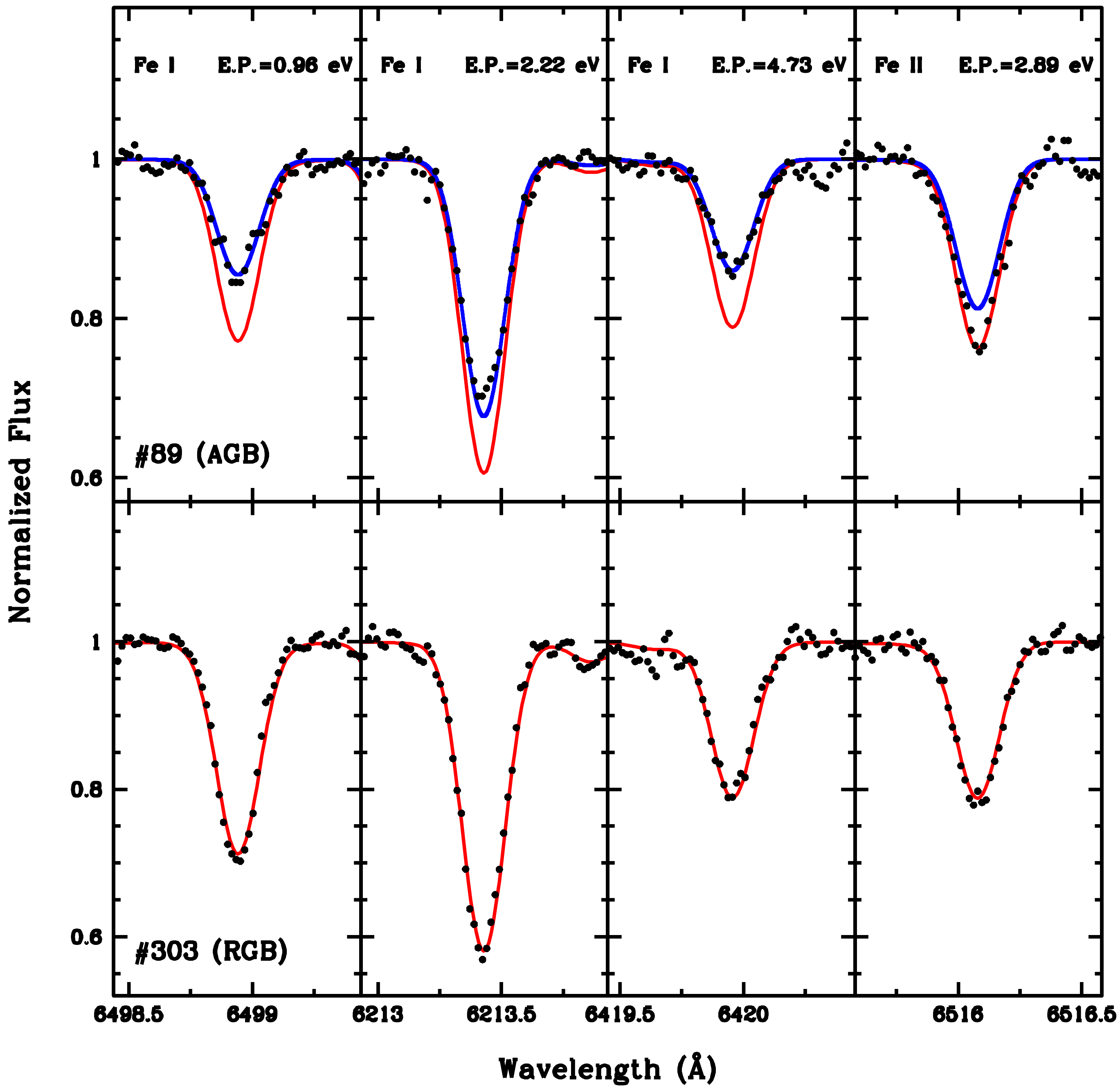




They are genuine AGB stars



Fe I E.P.=0.96 eV
Fe I E.P.=2.22 eV
Fe I E.P.=4.73 eV
Fe II E.P.=2.89 eV
#89 (AGB)
#303 (RGB)
Normalized Flux
Wavelength (Å)
Fe abundance from Fe I lines
Fe abundance from Fe II lines
Fe abundance from Fe I lines



Discrepancy between the Fe abundances does not depend on E.P. and EW

The lesson from NGC3201

If your sample includes
both AGB and RGB stars

Spectroscopic logg
(Fe I ~ Fe II)

→ FeI biased by NLTE:
a spurious Fe spread

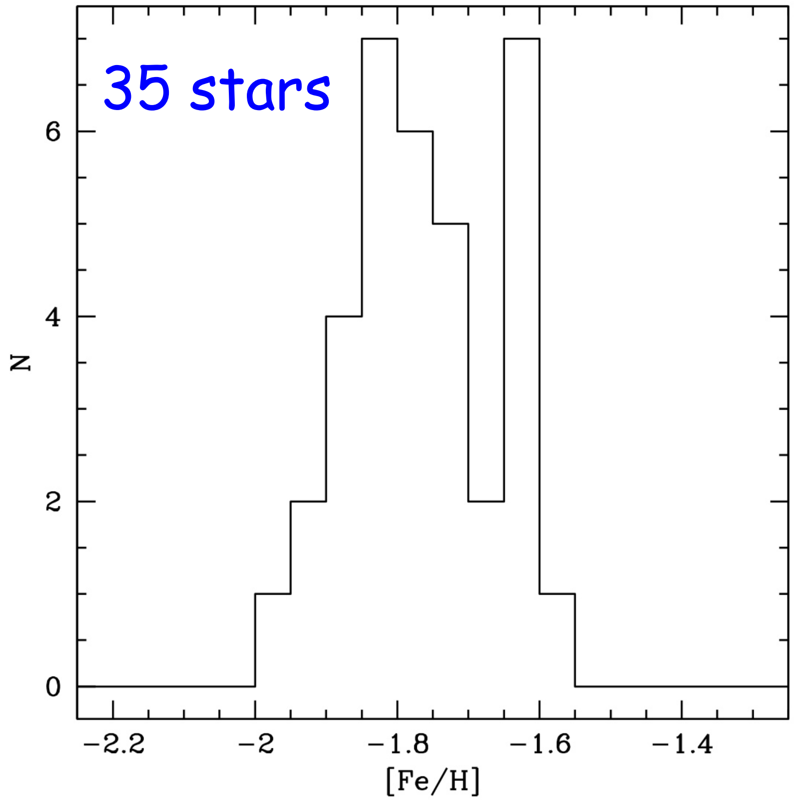
Photometric logg

→ **Fe I lines**
a spurious Fe spread

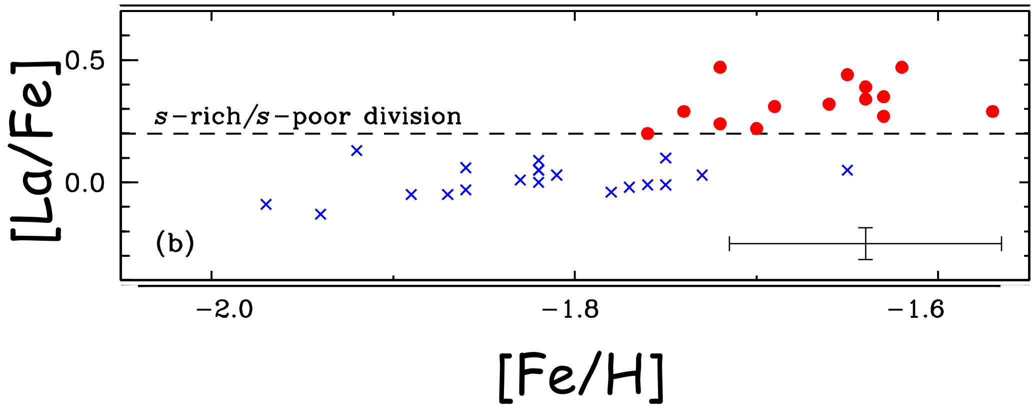
→ **Fe II lines**
No Fe spread

The case of M22

data from Marino+09,+11



Marino+11



Two groups of stars with:

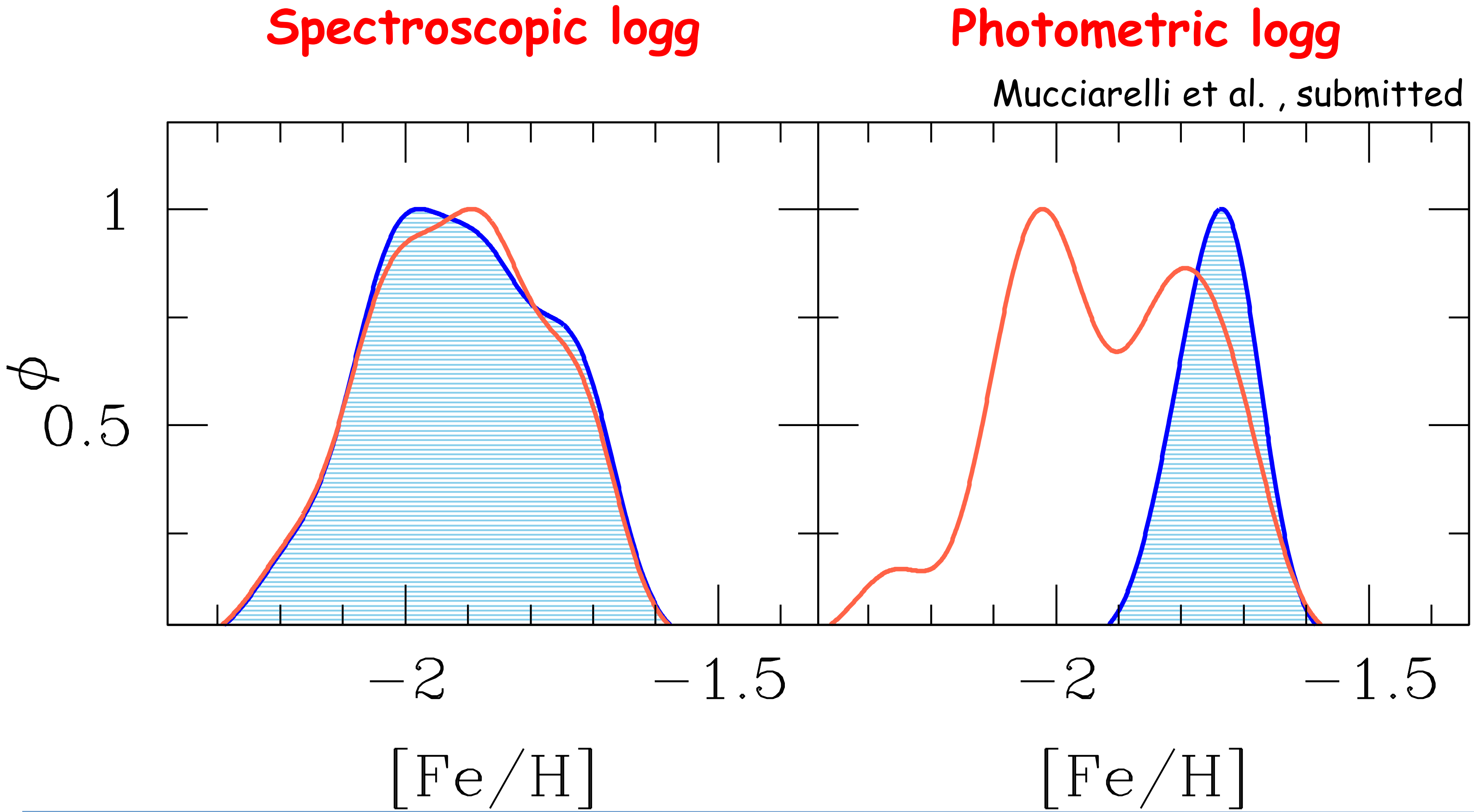
- different [Fe/H]
- different s-process elements
- different C+N+O ...

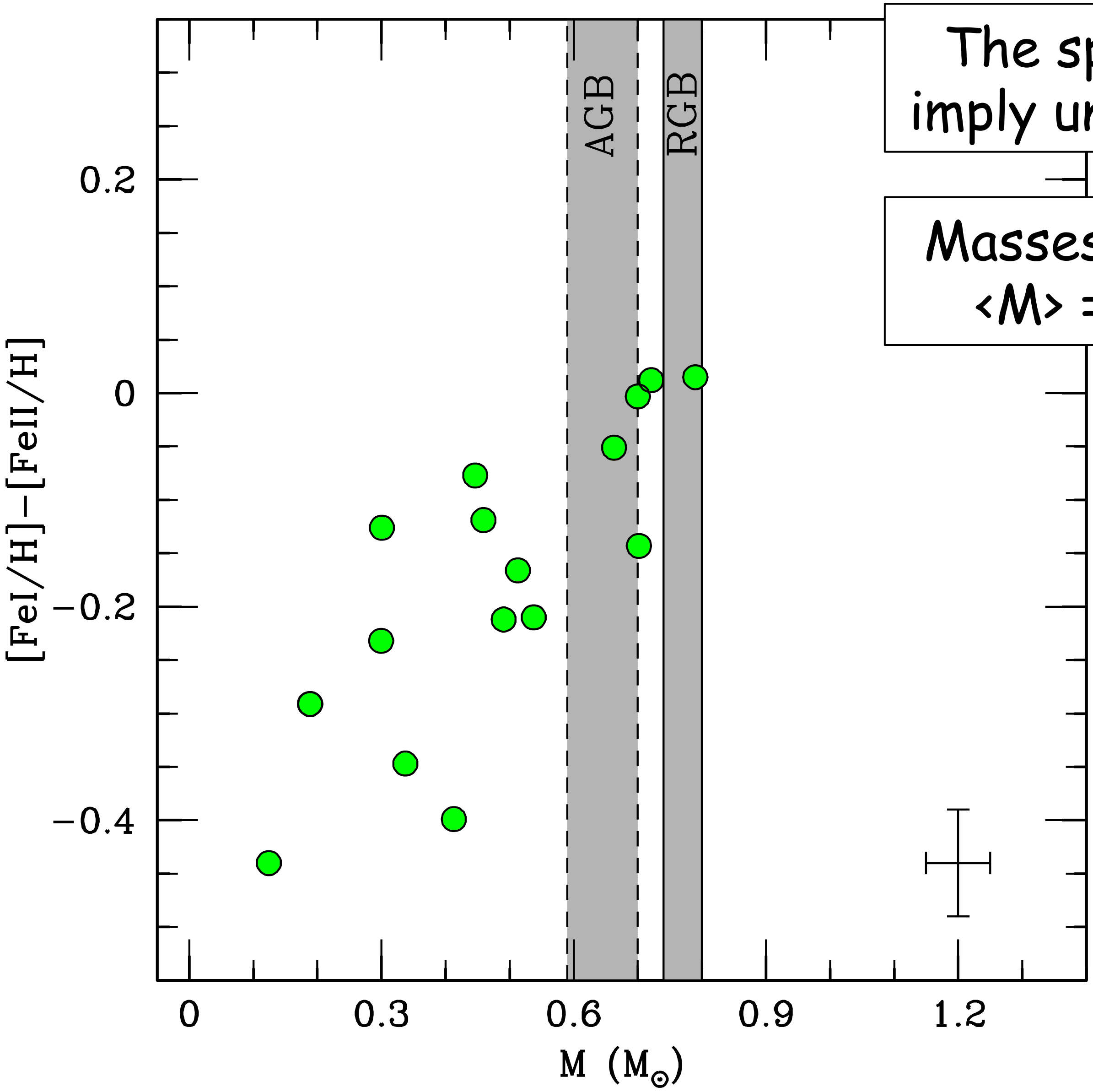
... but based on spectroscopic logg

Re-analysis of the 17 stars by Marino+09 (FLAMES-UVES)

An additional (and more complex) case … M22

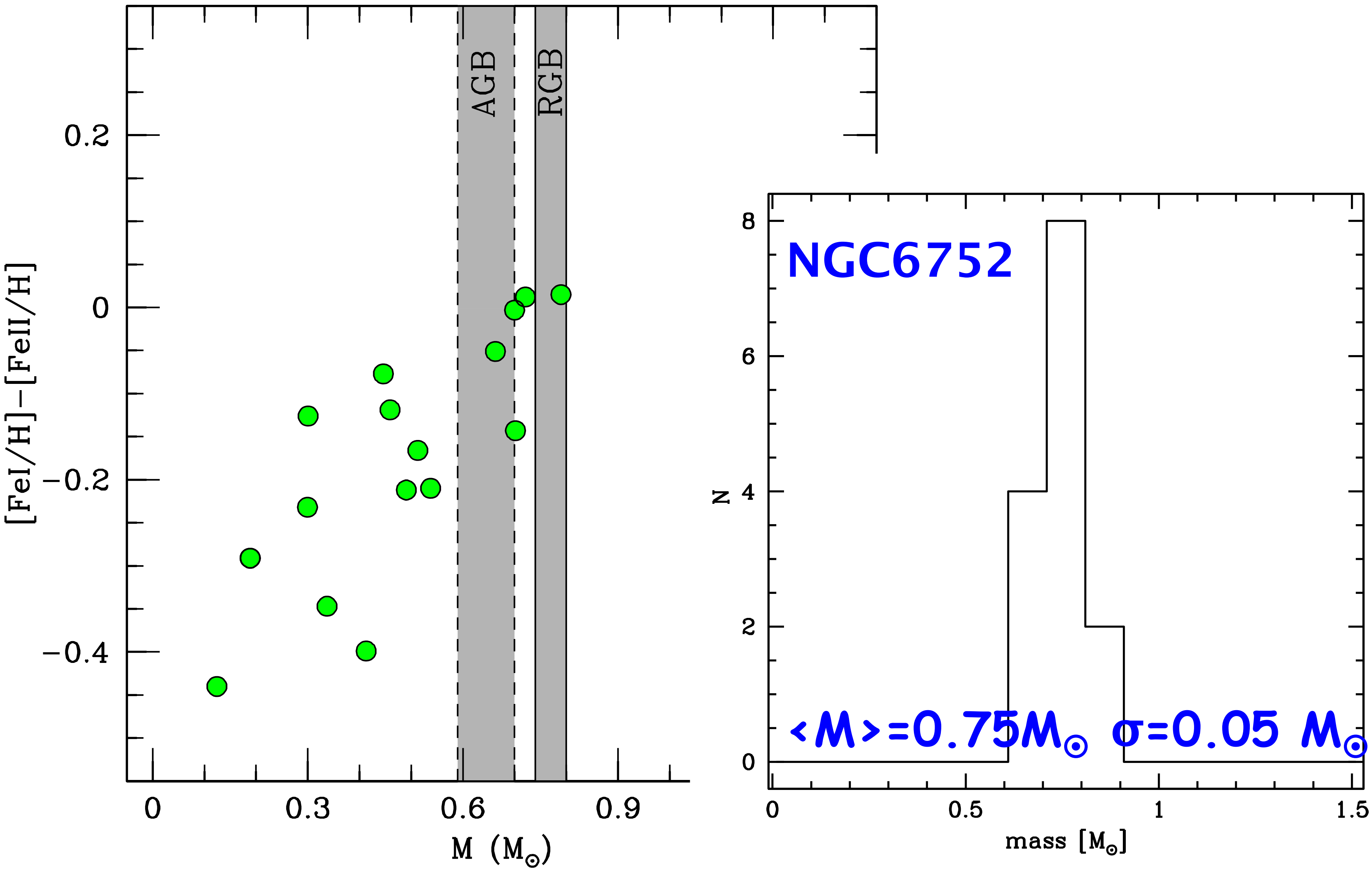
When we use photometric logg and Fe II lines ….
M22 is mono-metallic

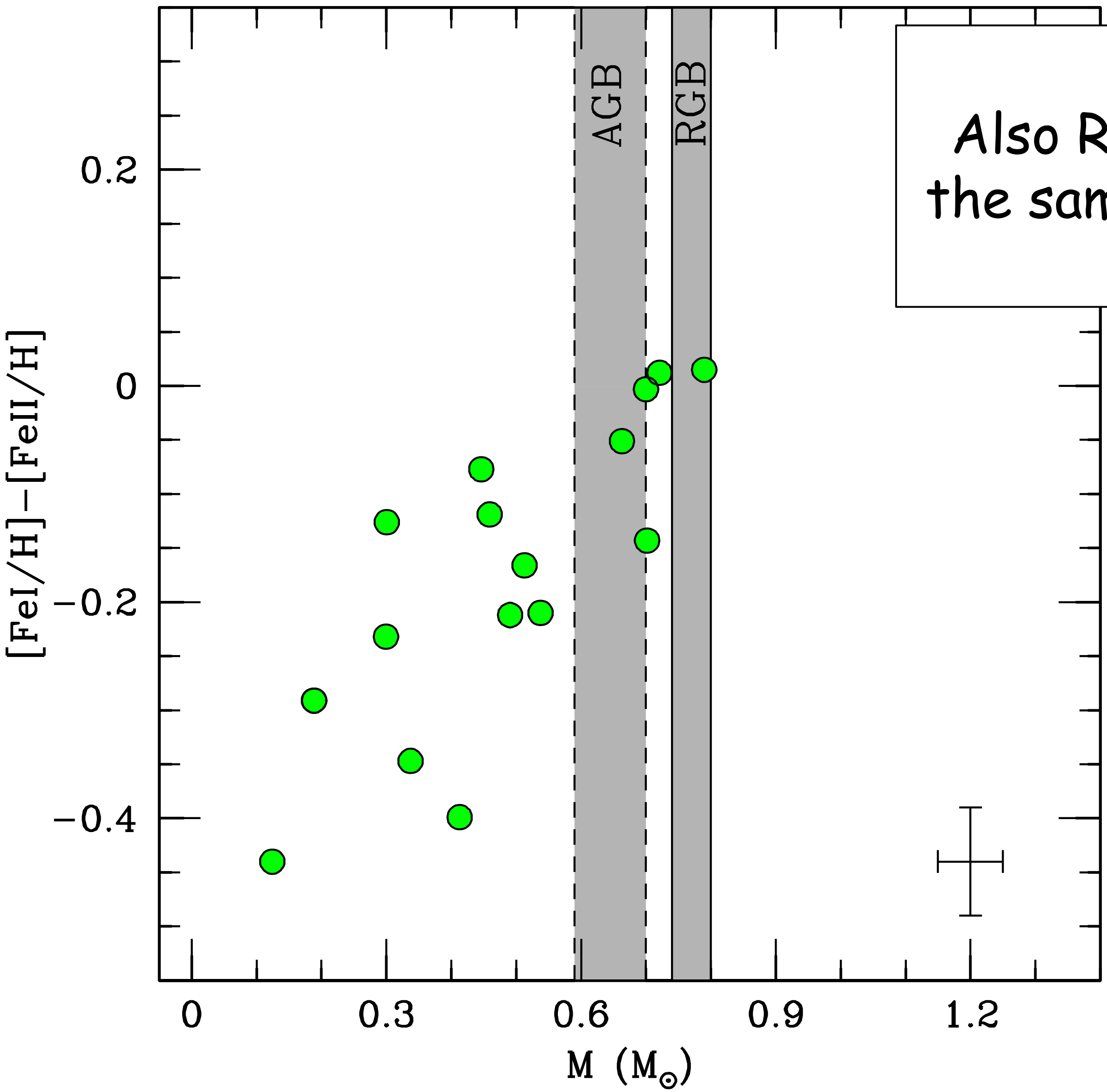




The spectroscopic gravities imply unreliable stellar masses

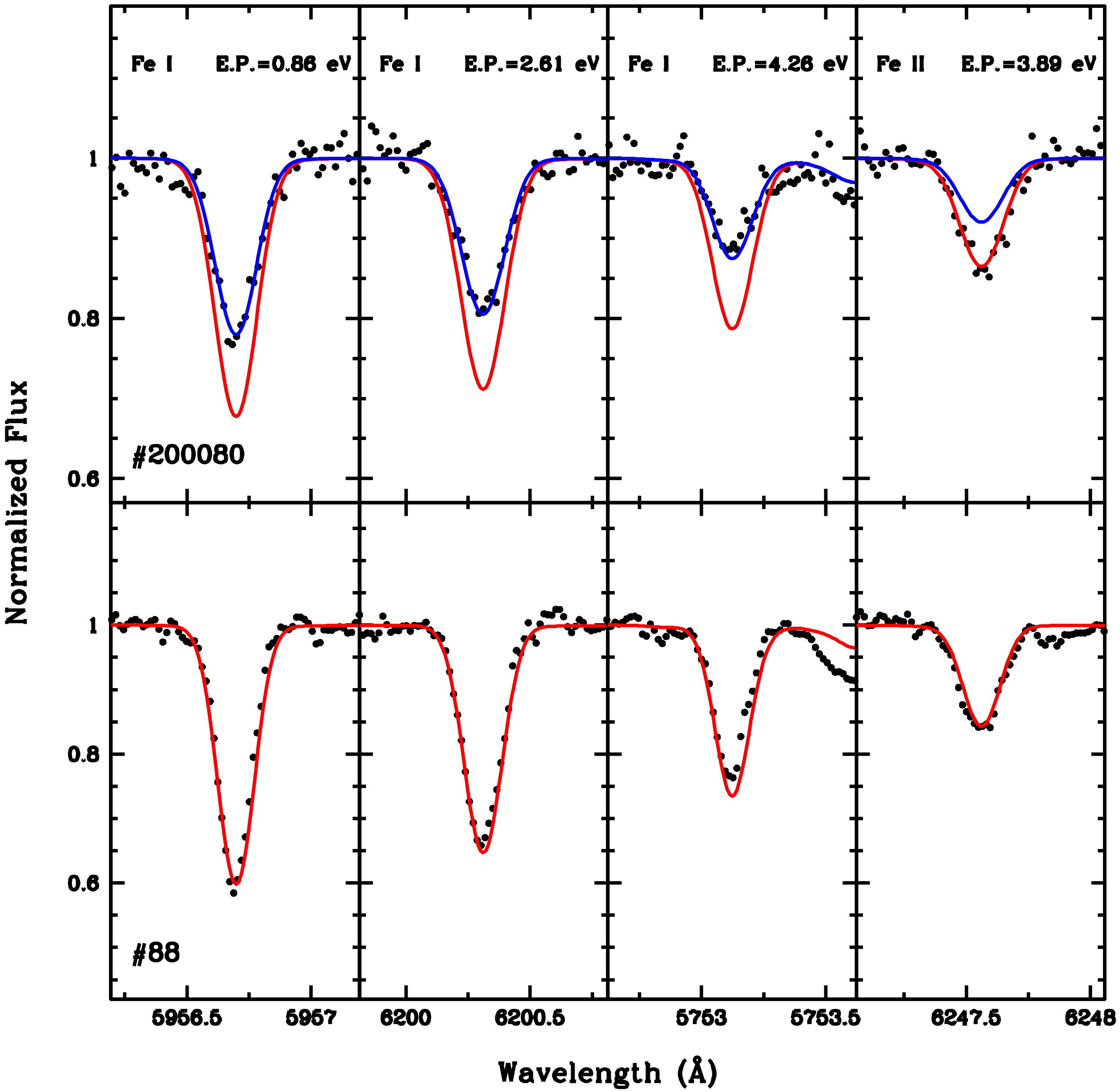
Masses from ~0.1 to ~0.8 $M_\odot$
$\langle M \rangle = 0.46 M_\odot$ $\sigma = 0.2\ M_\odot$


AGB
RGB
[FeI/H]−[FeII/H]
M ($M_\odot$)
0.2
0
−0.2
−0.4
0
0.3
0.6
0.9
NGC6752
N
mass [$M_\odot$]
$<M>=0.75M_\odot$ $\sigma=0.05$ $M_\odot$



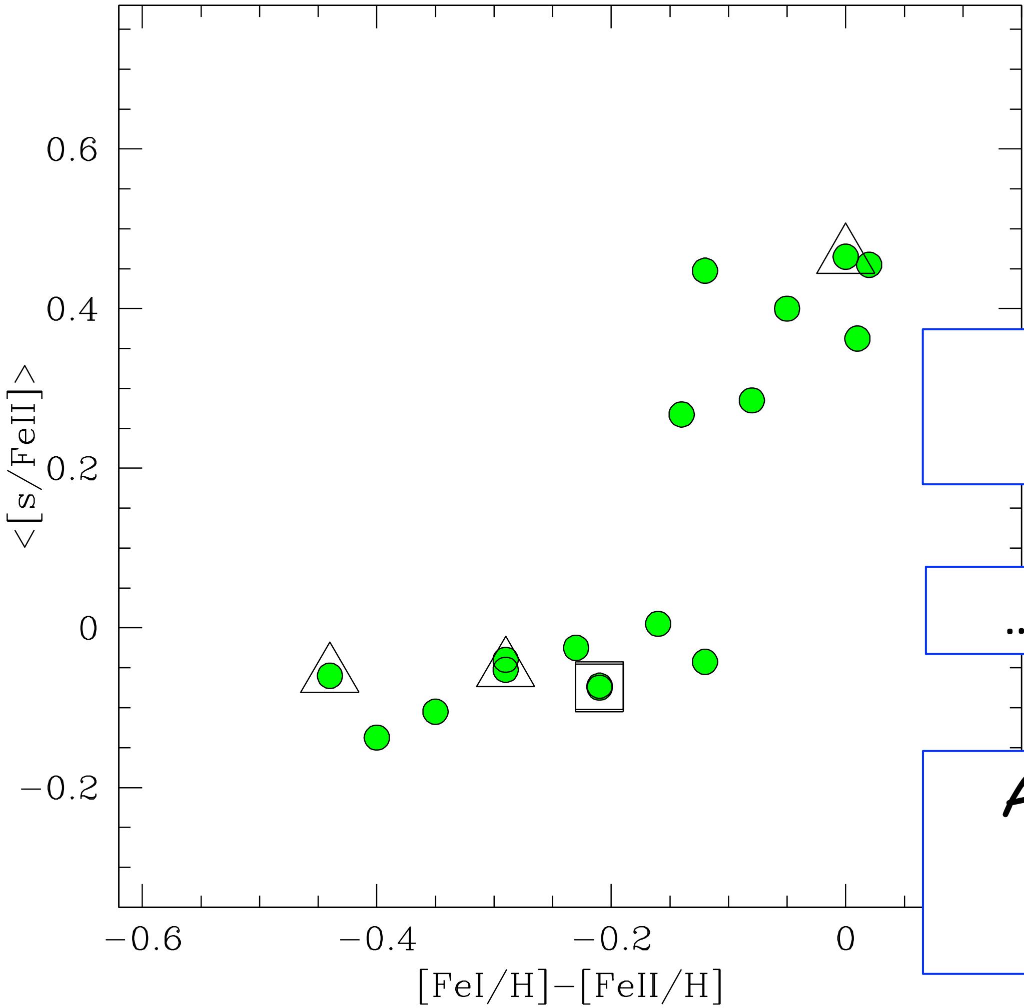
ACHTUNG !!!

Also RGB stars in M22 show the same problem in FeI lines.


Fe I E.P.=0.86 eV
Fe I E.P.=2.61 eV
Fe I E.P.=4.26 eV
Fe II E.P.=3.89 eV
#200080
#88
Normalized Flux
Wavelength (Å)
0.6
0.8
1
5956.5
5957
6200
6200.5
5753
5753.5
6247.5
6248

The case of M22

An intrinsic variation in the s-process elements.
Two groups of stars: s-poor and s-rich



4 out 5 AGB stars show NLTE effects....

... but also some RGB stars

A correlation between the s-process elements and [FeI/H]-[FeII/H]

Conclusions

- The AGB stars show NLTE effects at variance with the RGB stars
- The best way to avoid spurious effects is:
  Fe II lines + photometric logg
- With this approach NGC3201 turns out to be mono-metallic
- Also M22 is mono-metallic but the NLTE effects are observed also among the RGB stars (effects of anomalous chemical composition?)

Future perspectives

The End