Spurious and real iron spreads in globular clusters

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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

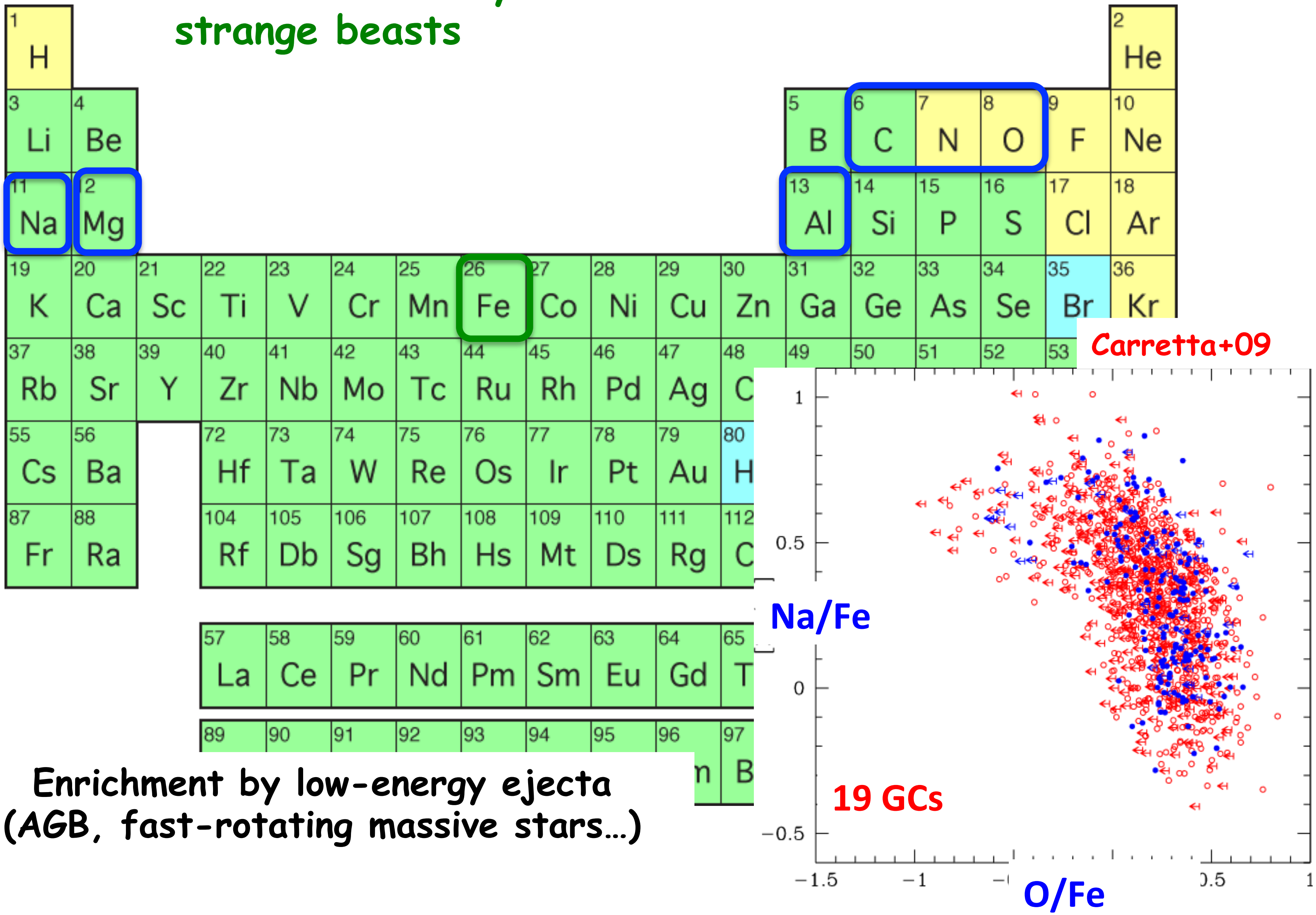
GCs are useful tools to study

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

………..

Observed to vary in all GCs

Observed to vary in a few strange beasts



Enrichment by low-energy ejecta
(AGB, fast-rotating massive stars…)

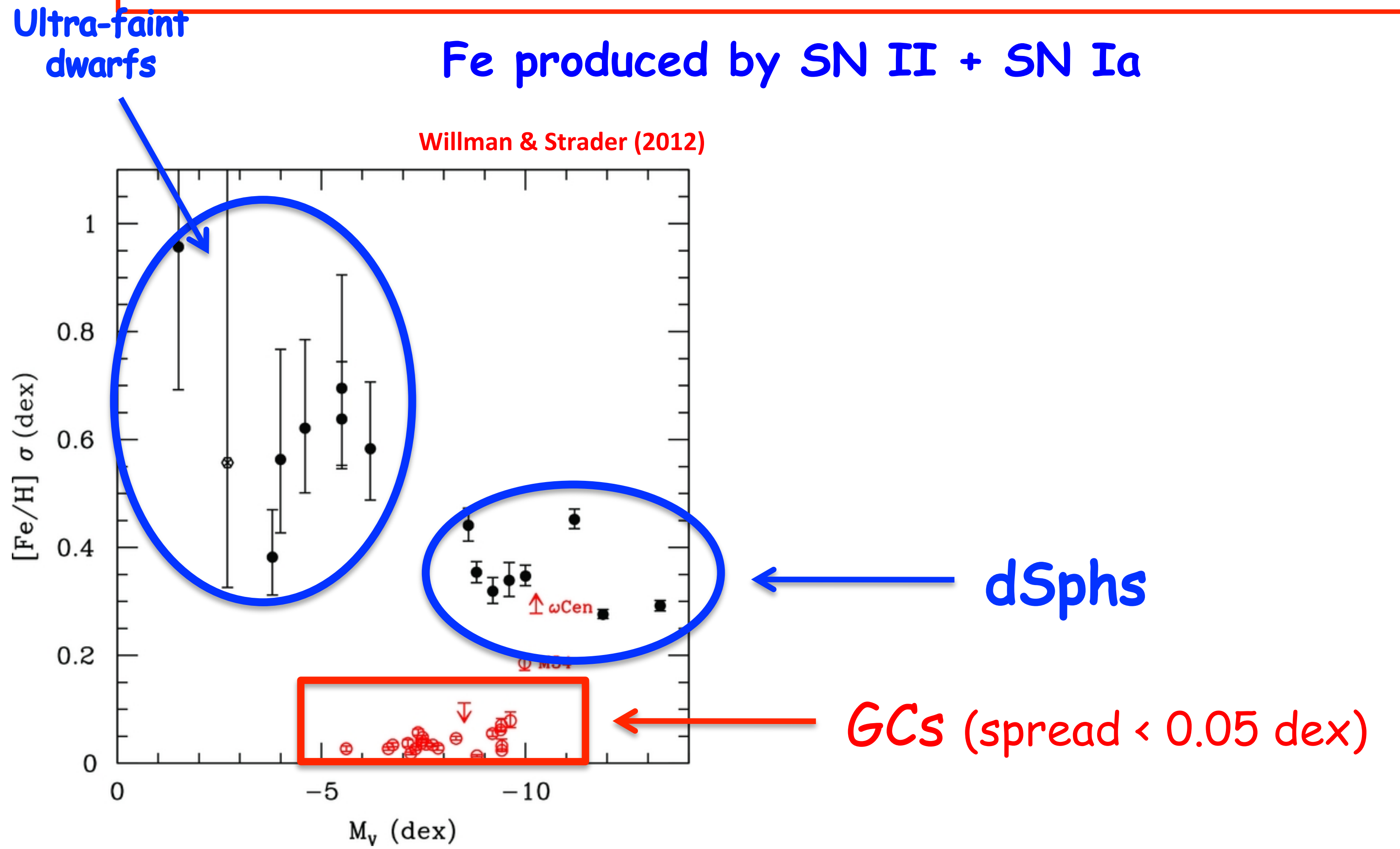
Fe (and Fe-peak elements)

GOLDEN RULE

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

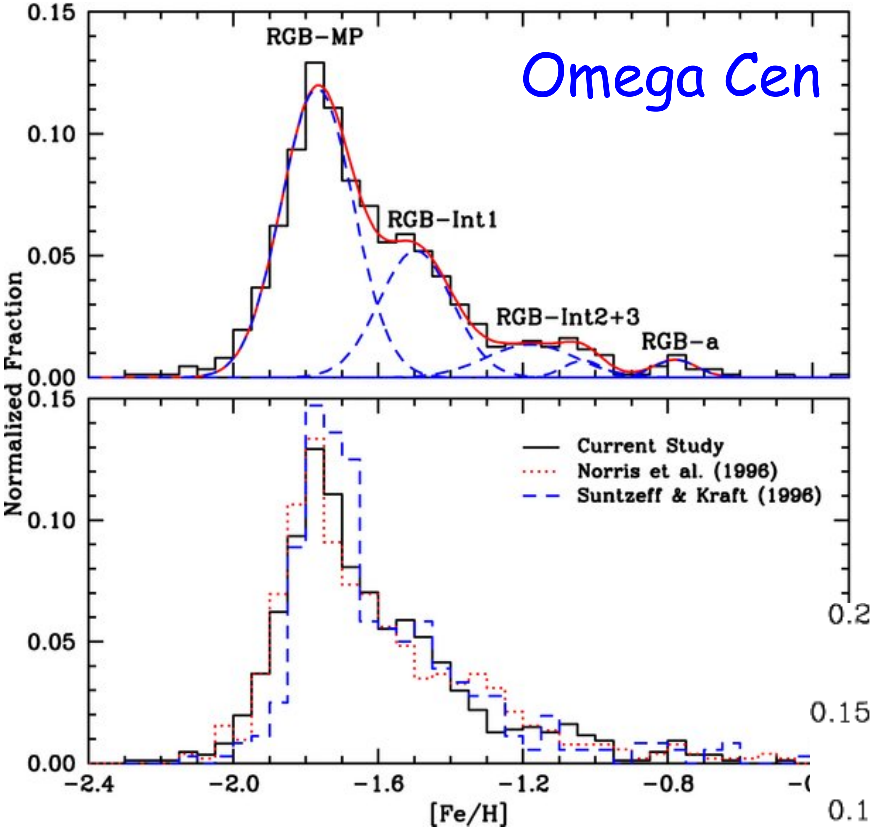
Fe produced by SN II + SN Ia

Willman & Strader (2012)

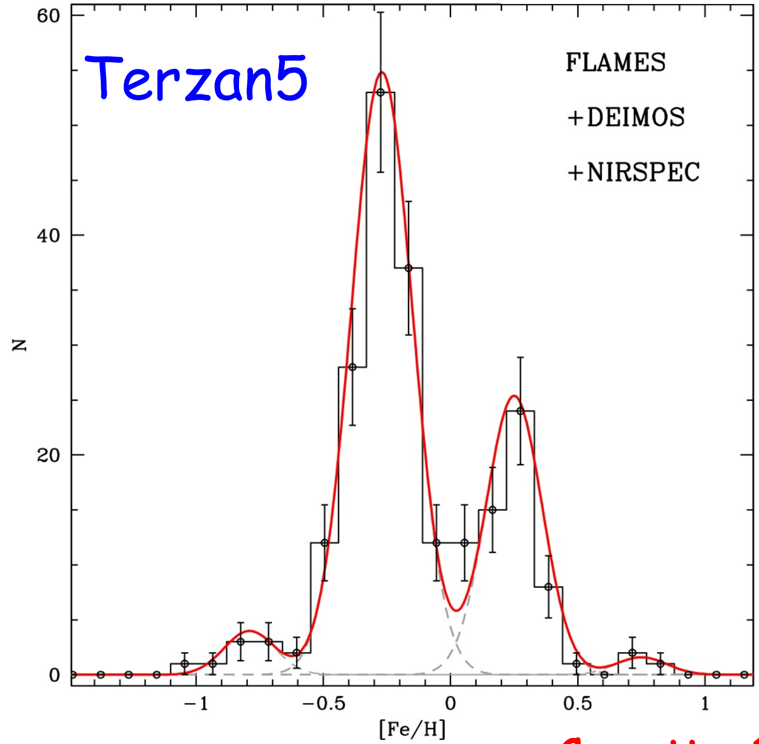


Strange beasts … Fe spreads !!!

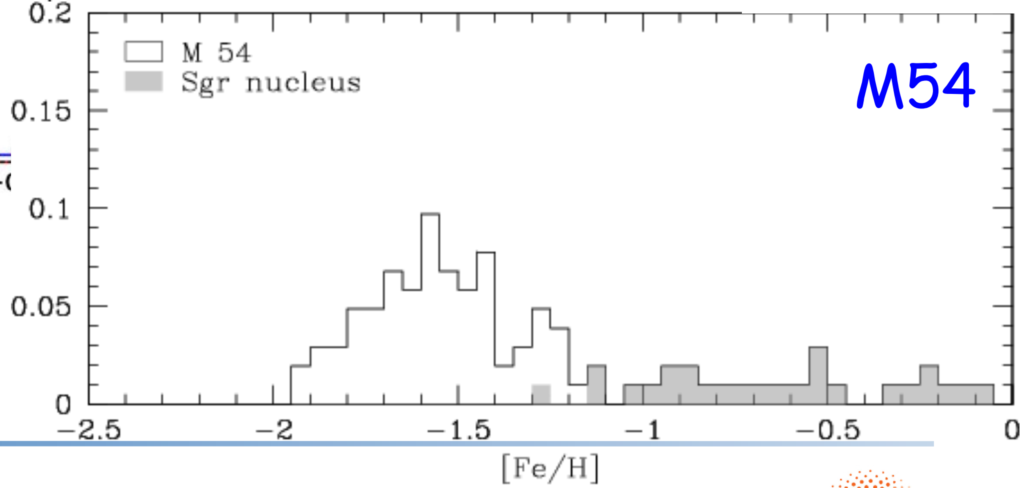
Johnson & Pilachowski (2009)



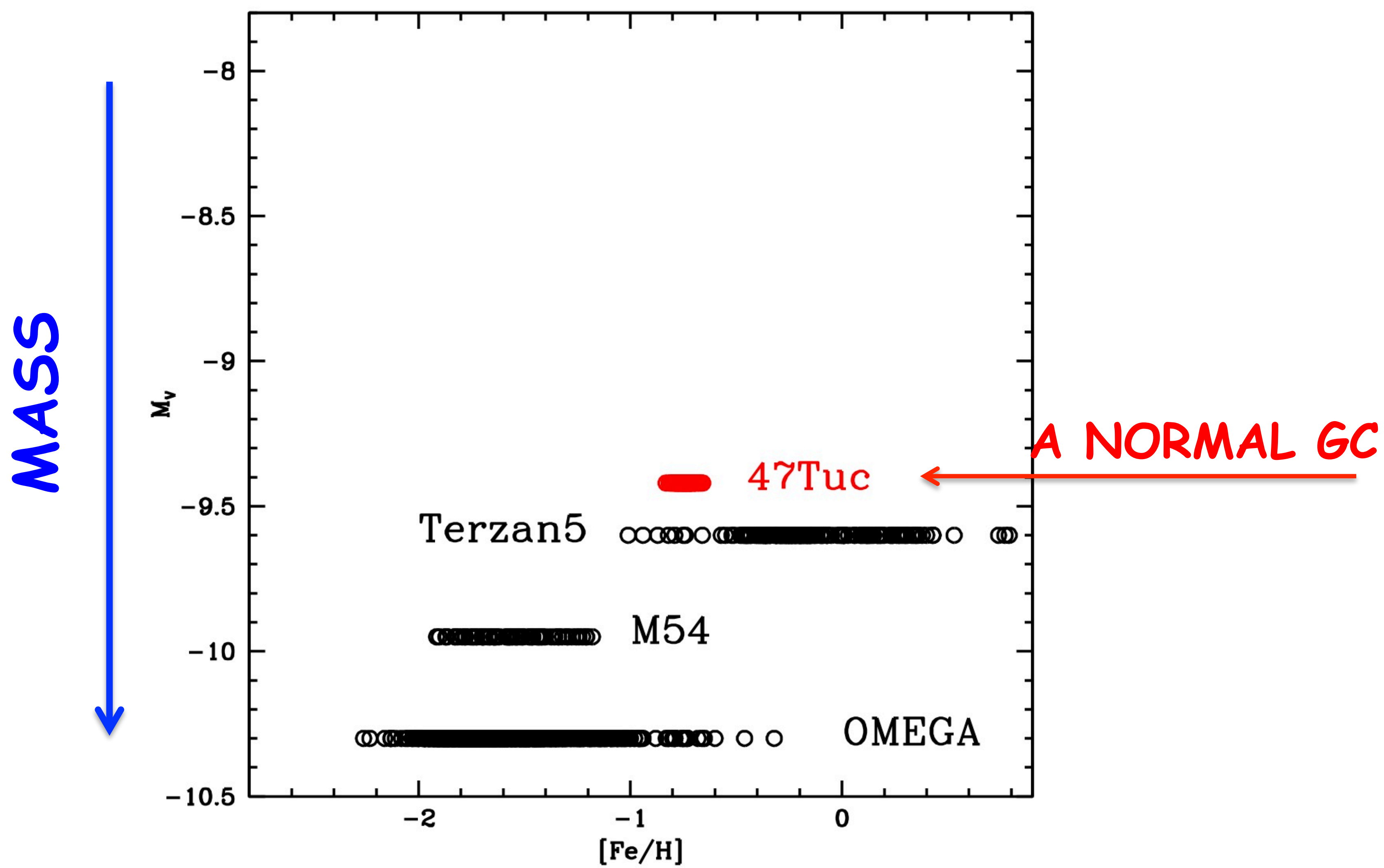
Massari+14



Carretta+10



Not genuine GCs !!!!!


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

Strange beasts … Fe spreads !!!

- Omega Centauri
- Terzan 5
- M54

New GCs with measured Fe spreads

M22 (Marino+09,Marino+11)
M2 (Yong+14)
NGC3201 (Simmerer+13)
NGC1851 (Carretta+10)
→ NGC5286 (Marino+15)
→ M19 (Johnson+15)

} High-res spec

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

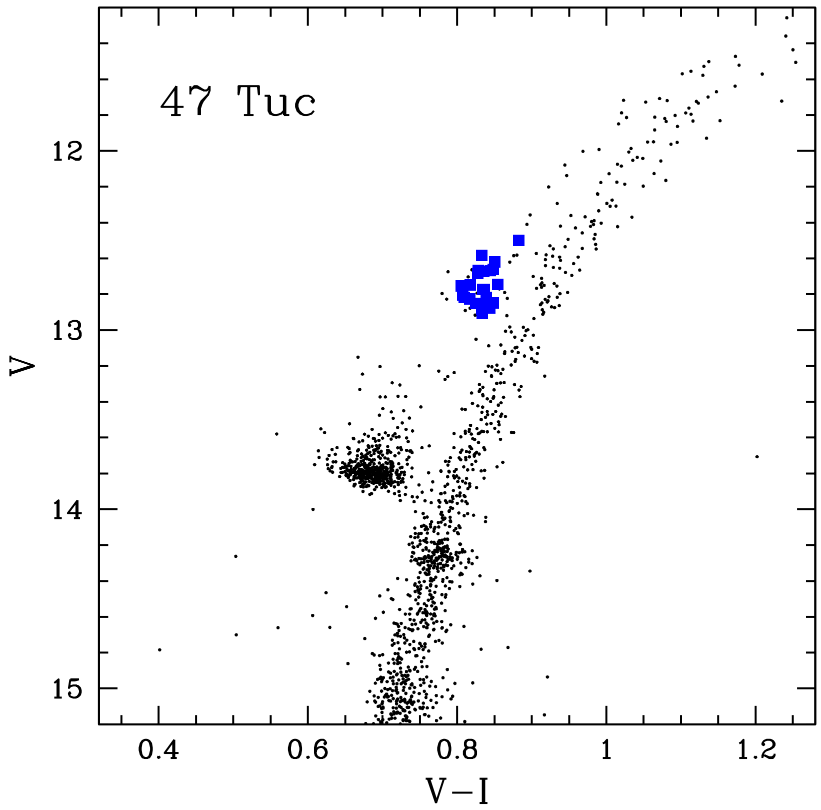
A growing number of *anomalous* GCs

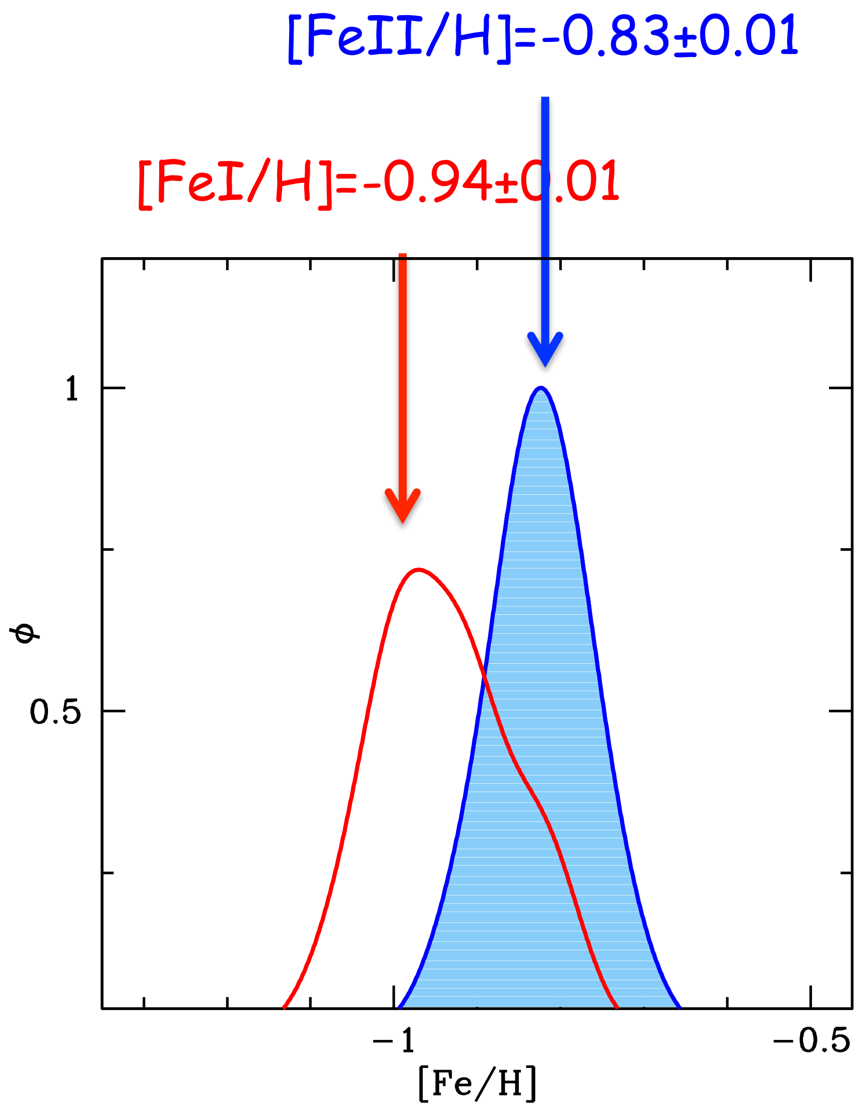
A different formation/evolution mechanism?

AGB stars in 47 Tucanae

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

Lapenna+14





Checks: analysis procedure

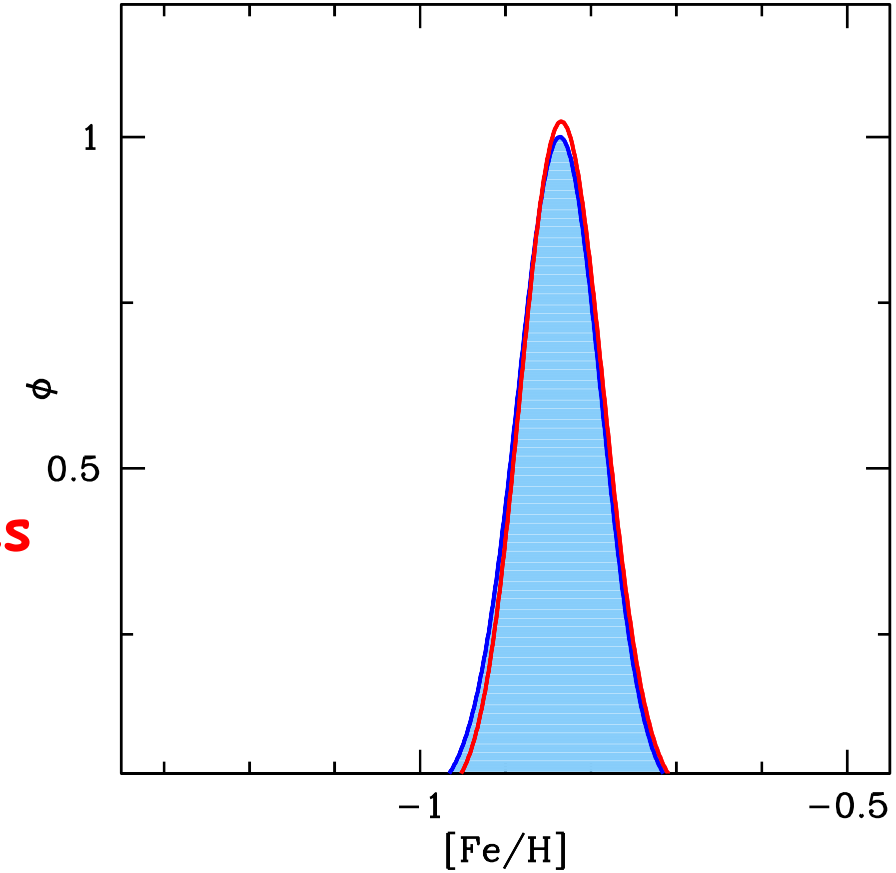
11 RGB stars observed
with FLAMES-UVES@VLT
R~45000 , S/N > 50

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

The problem is in the FeI lines in AGB stars only !!!

[FeI/H]=-0.83±0.01

[FeII/H]=-0.84±0.01



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 …

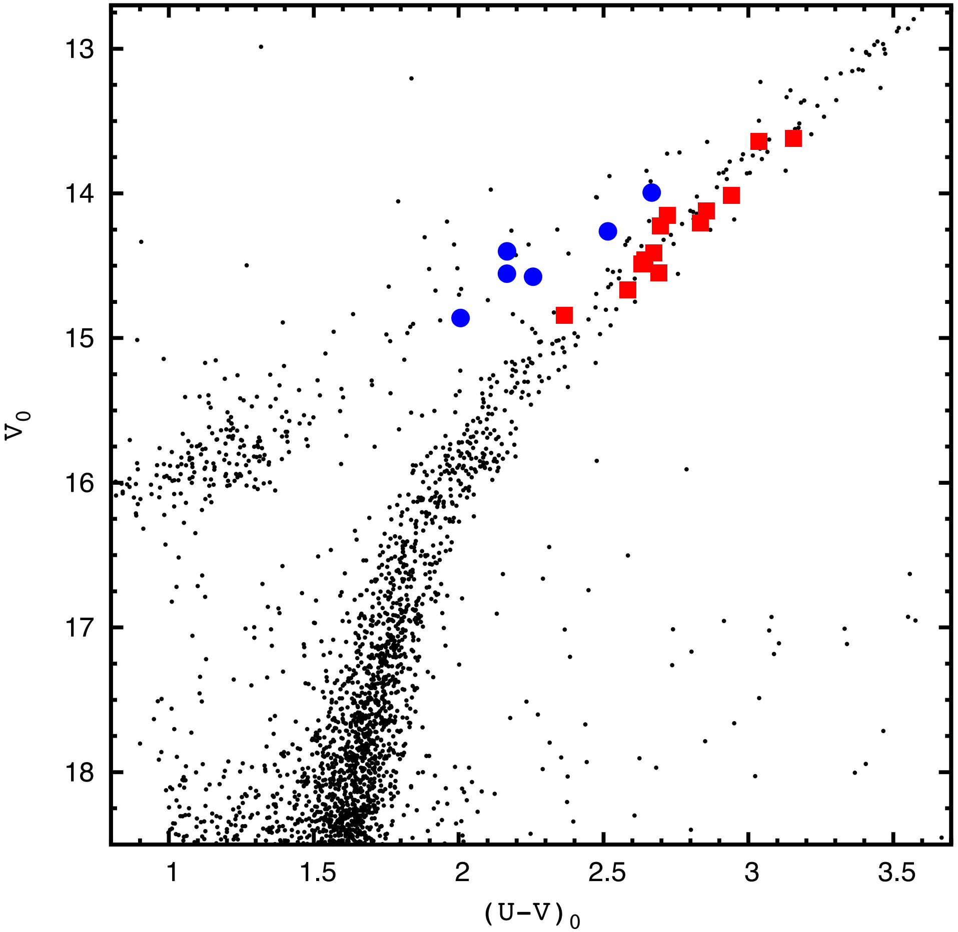
- [FeI/H] ~ [FeII/H] ~ -1.0 dex
  too low abundance, large difference with the RGB stars

- 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

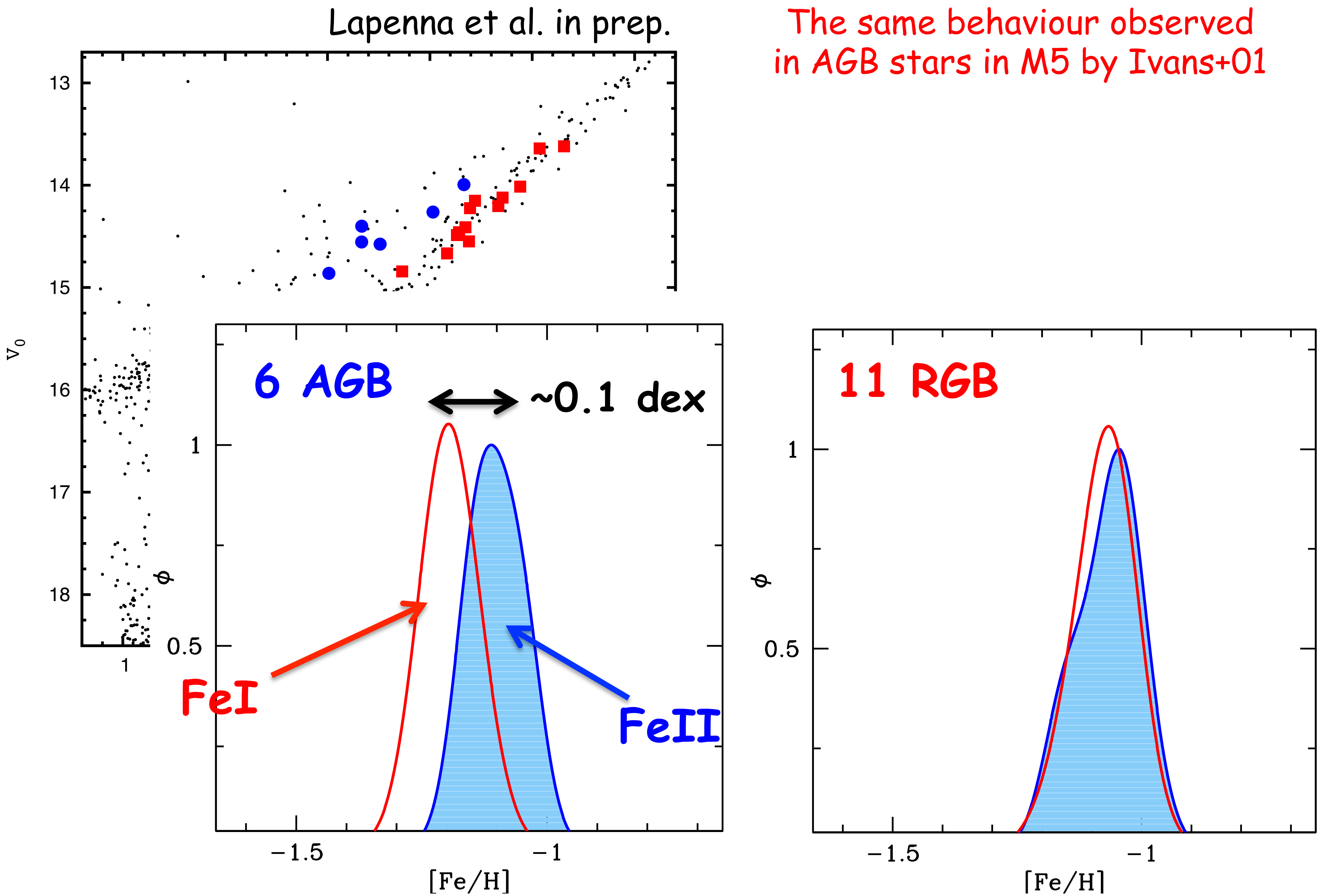
The case of M62

Lapenna et al. in prep.



The case of M62

The same behaviour observed
in AGB stars in M5 by Ivans+01



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) conditions

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

We are not still able to explain this effect
but we learn a lesson

(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

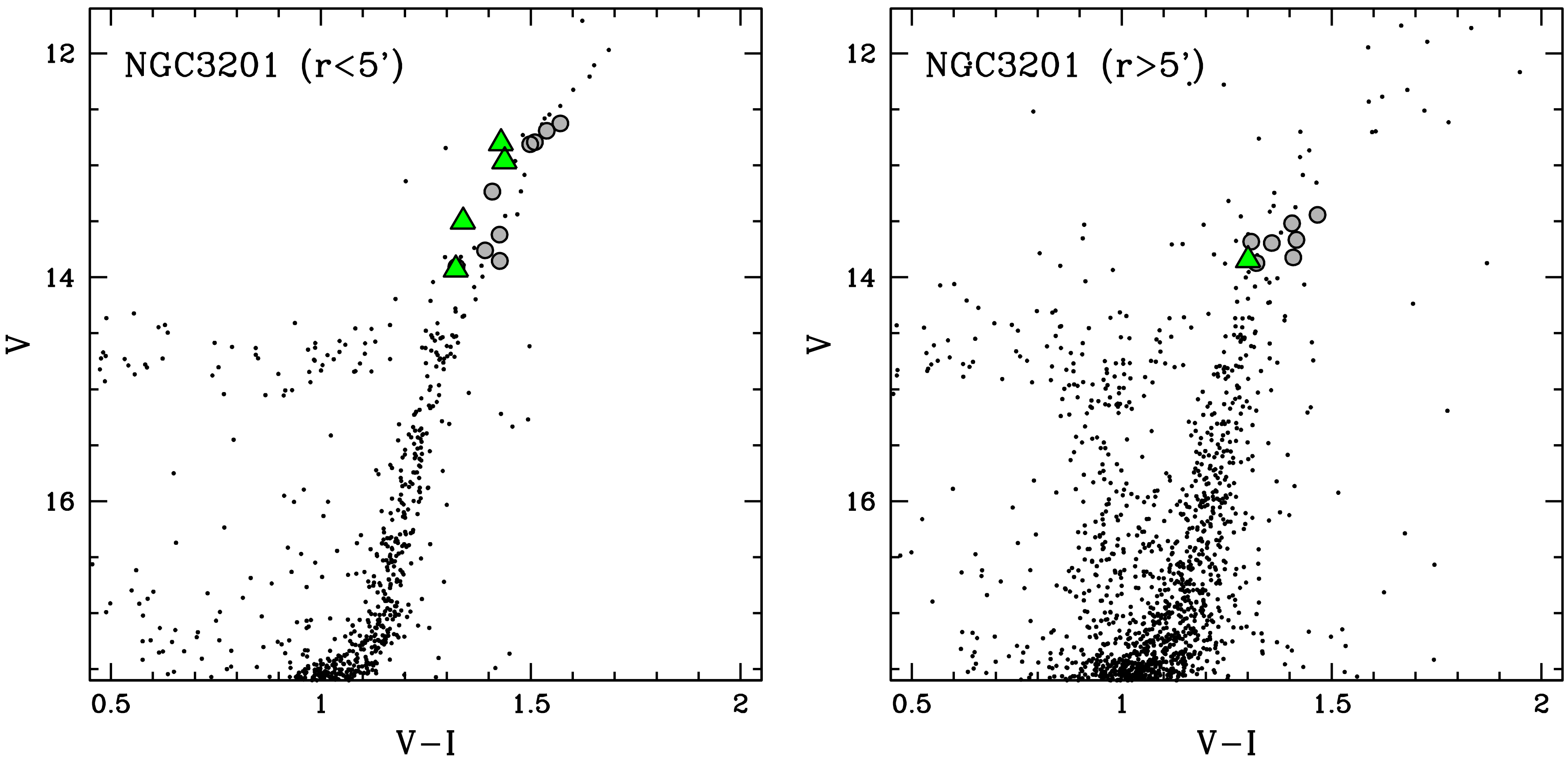
But … you need high-resolution, wide coverage spectra

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)



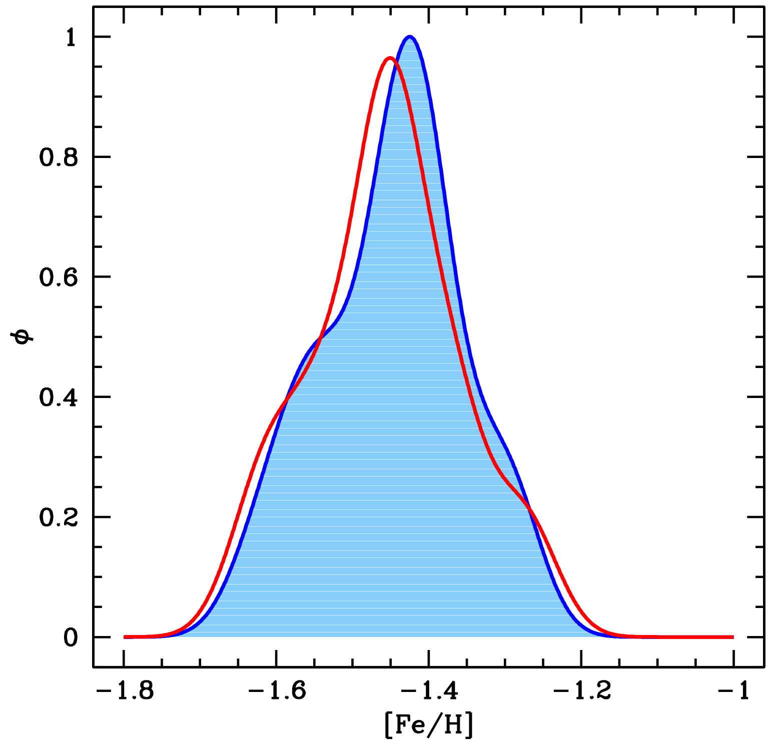
The case of NGC3201

Spectroscopic logg

[Fe I /H] = -1.46 (σ=0.10)

INTRINSIC FE SPREAD !!!

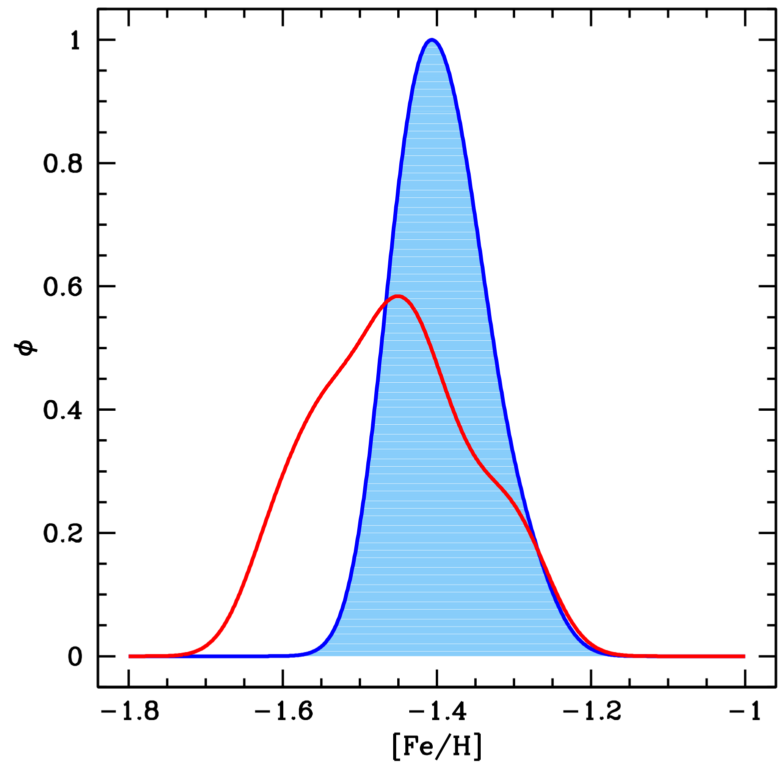
Mucciarelli+15

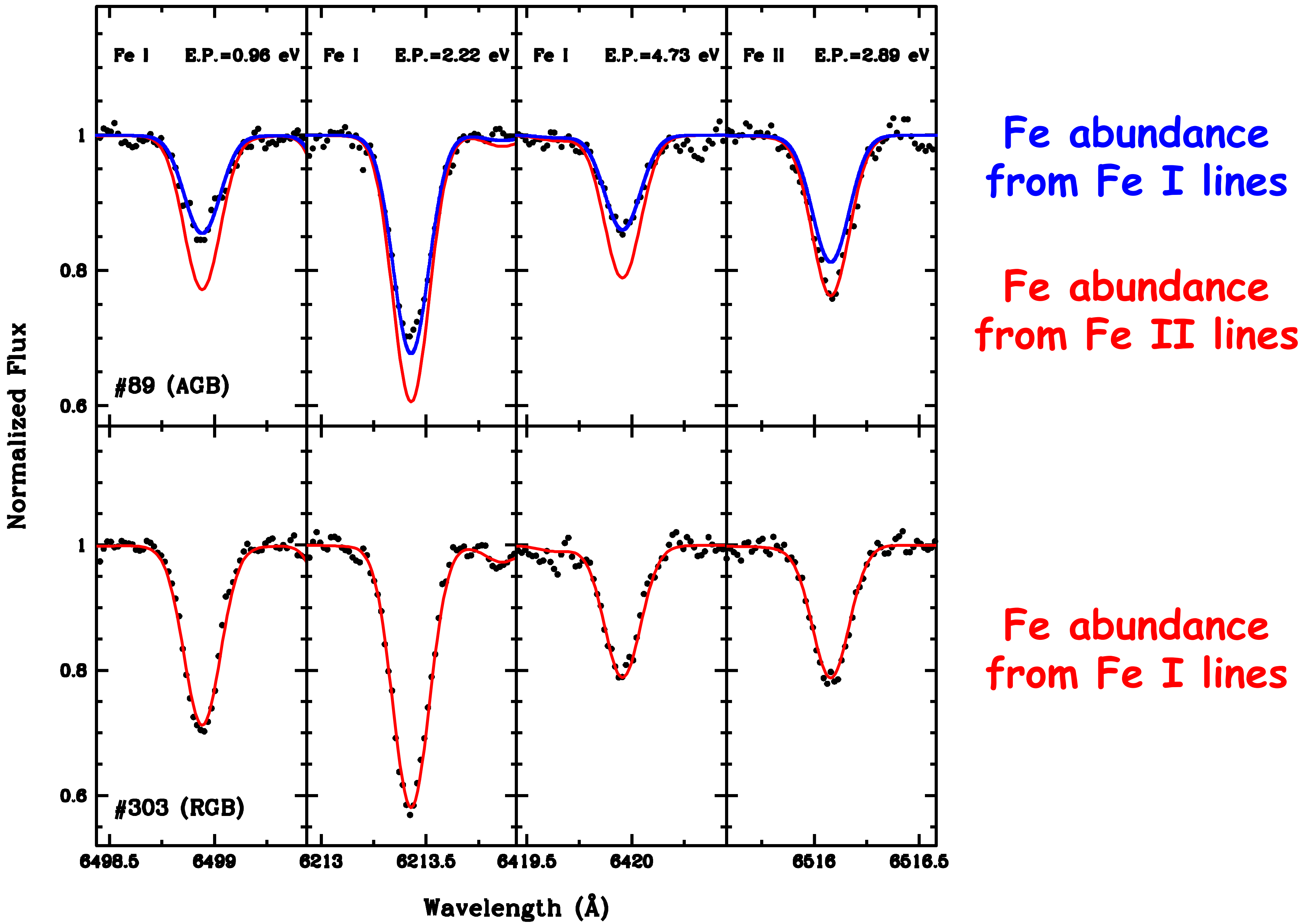


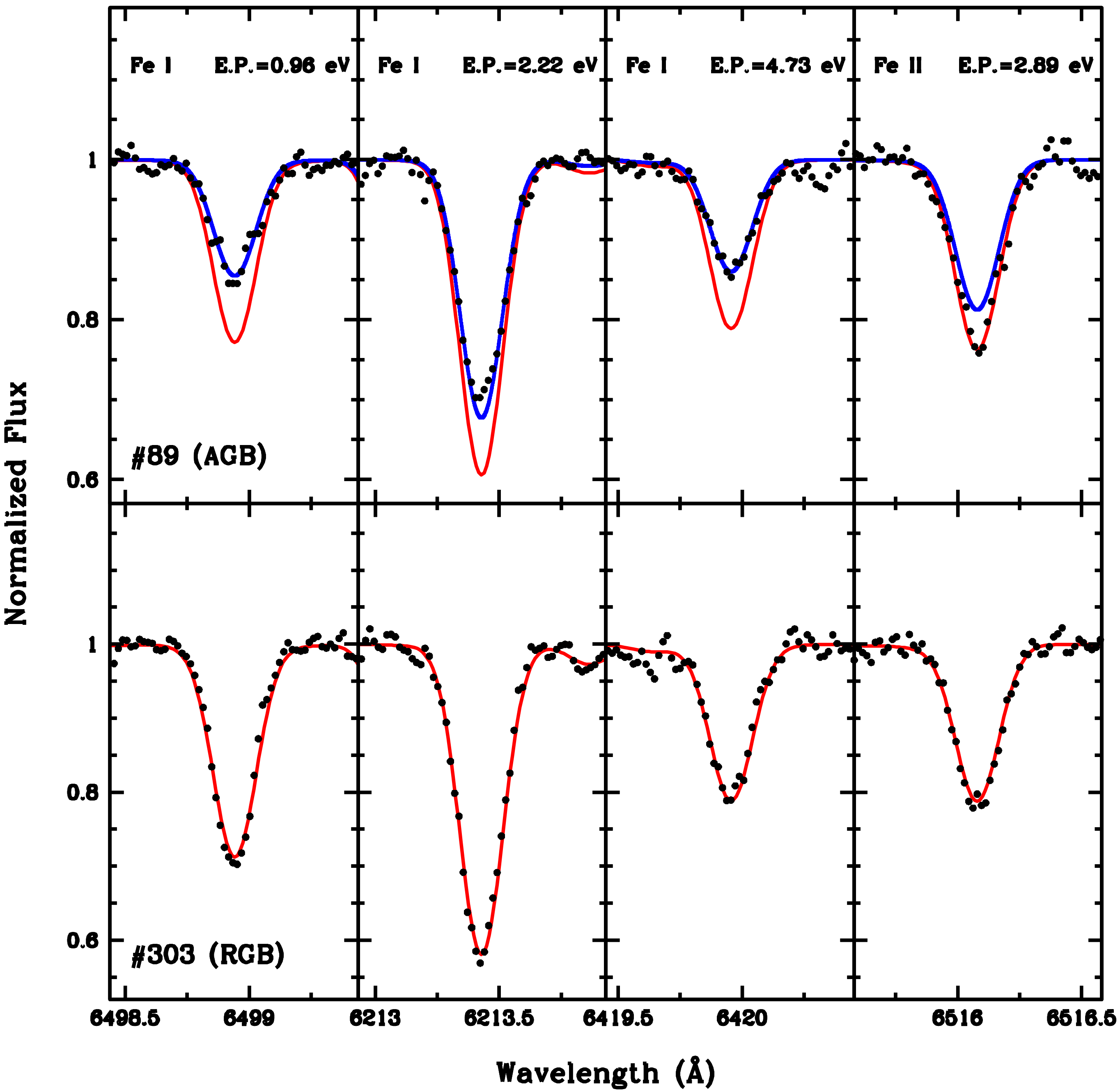
Photometric logg

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

Fe II : NO intrinsic Fe spread !!!



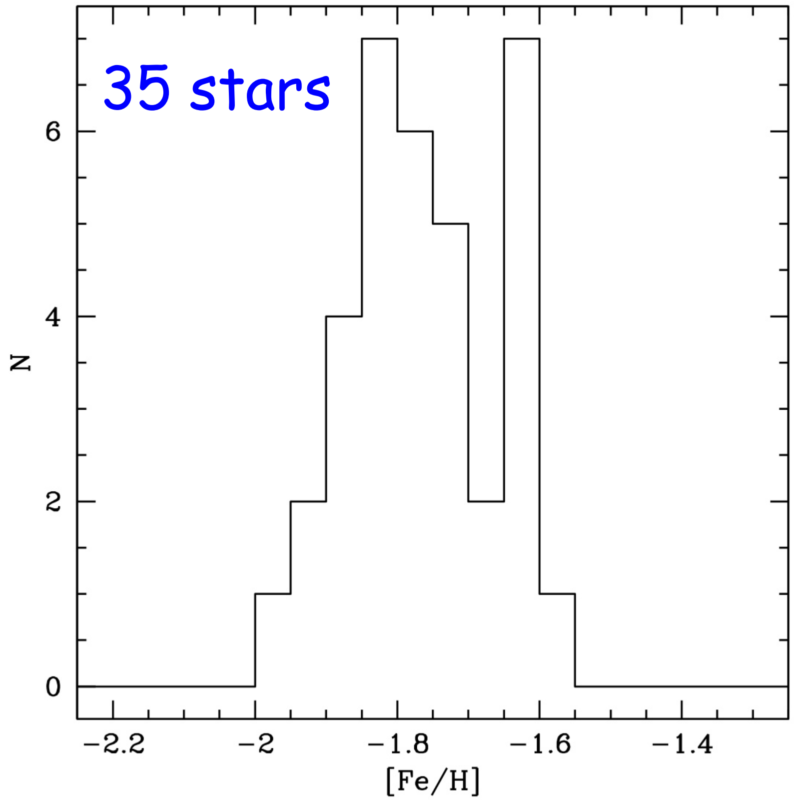

Fe I E.P.=0.96 eV
Fe I E.P.=2.22 eV
Fe I E.P.=4.73 eV
Fe II E.P.=2.89 eV
#89 (AGB)
#303 (RGB)
Normalized Flux
Wavelength (Å)
Fe abundance from Fe I lines
Fe abundance from Fe II lines
Fe abundance from Fe I lines



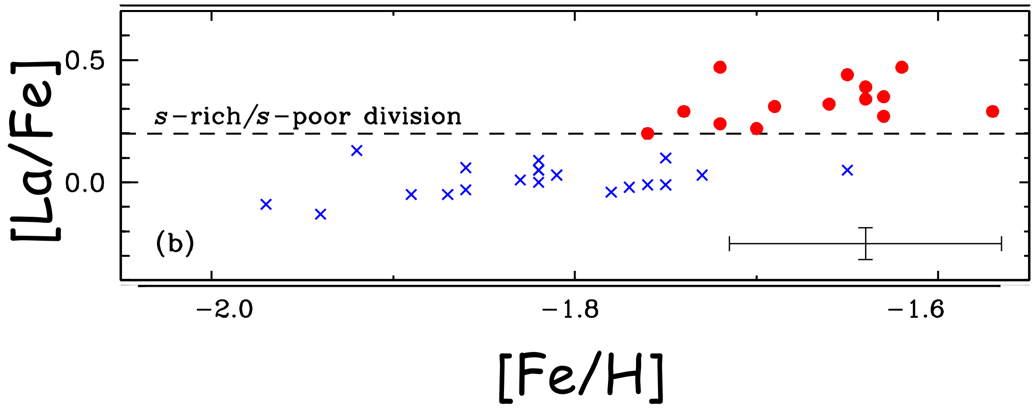
Discrepancy between the Fe abundances does not depend on E.P. and EW

The case of M22

data from Marino+09,+11



Marino+11



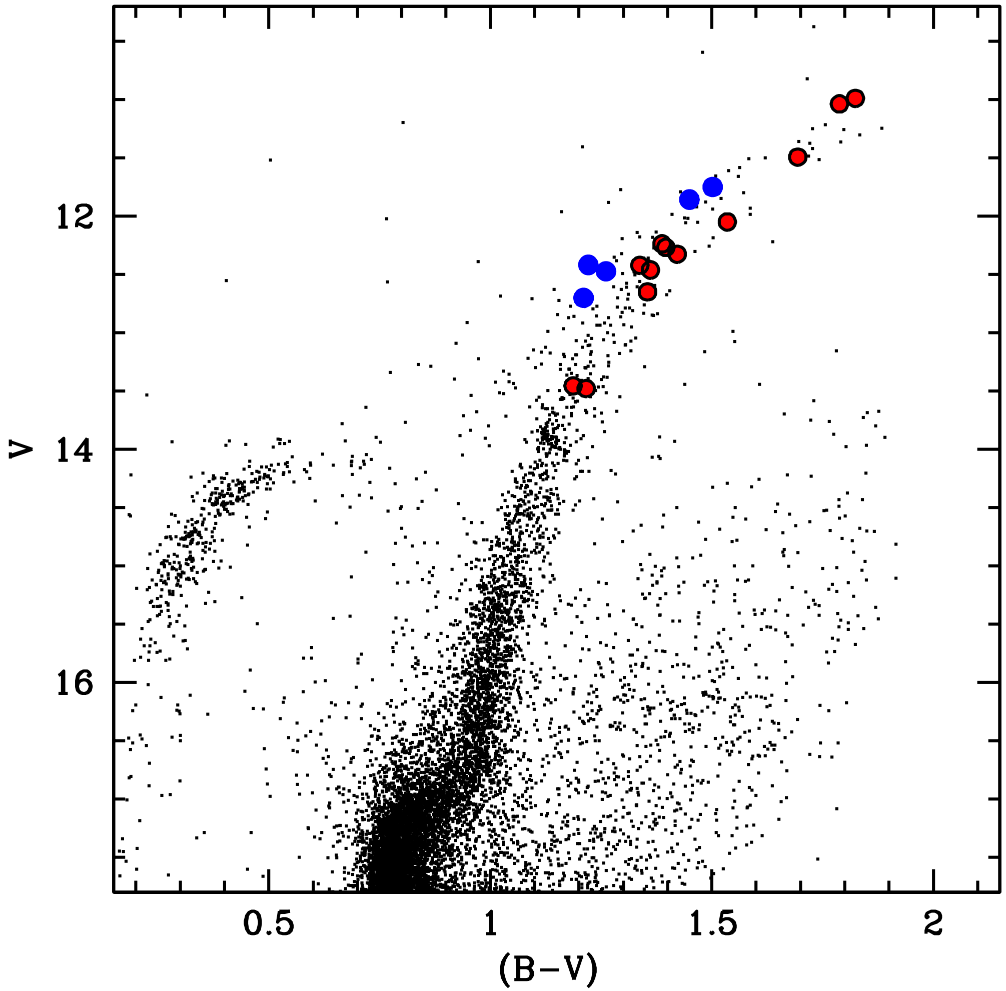
Two groups of stars with:
- different [Fe/H]
- different s-process elements
- different C+N+O …

… but based on spectroscopic logg

The case of M22

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

data from P. B. Stetson



Some AGB stars in the sample

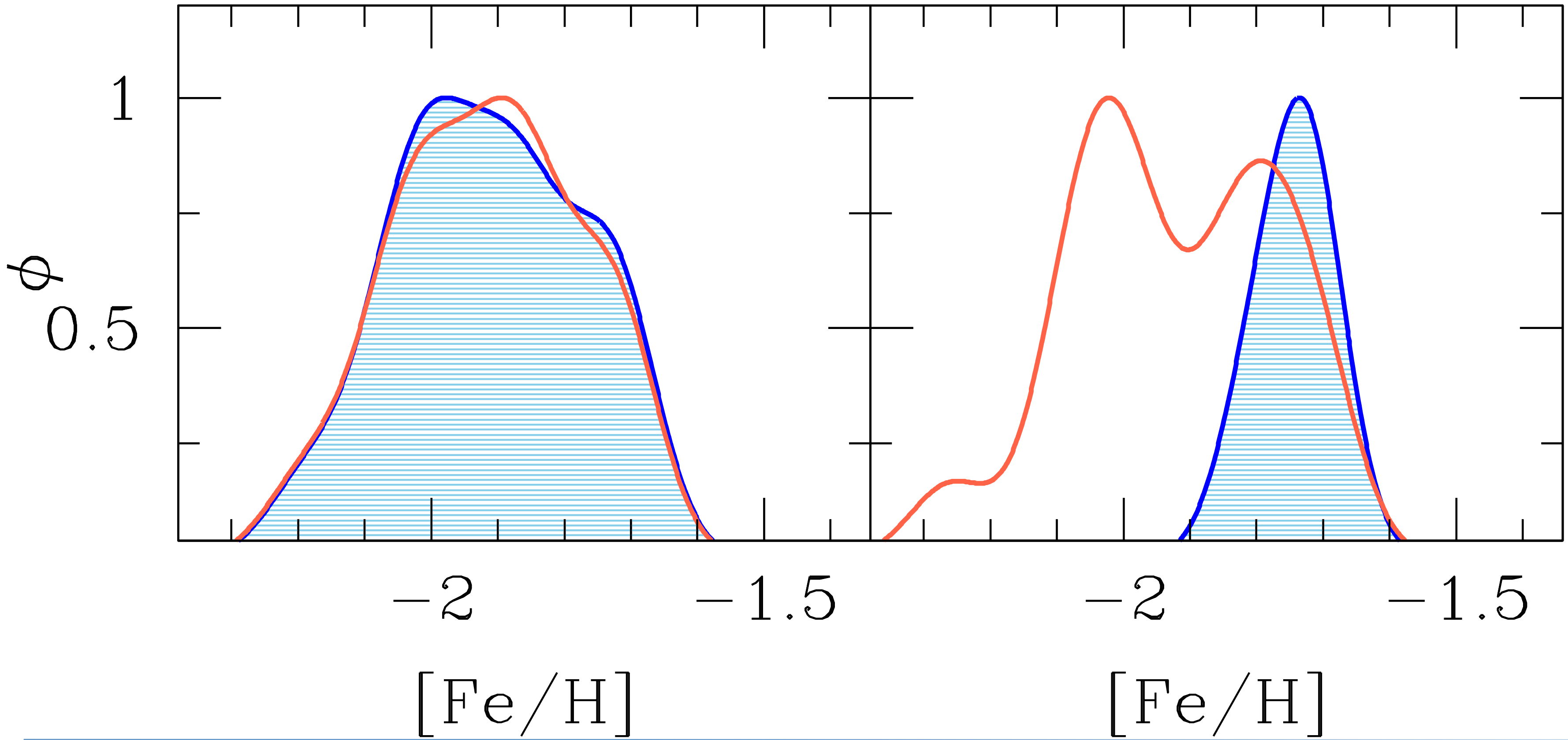
A possible bias like in NGC3201 ???

An additional (and more complex) case … M22

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

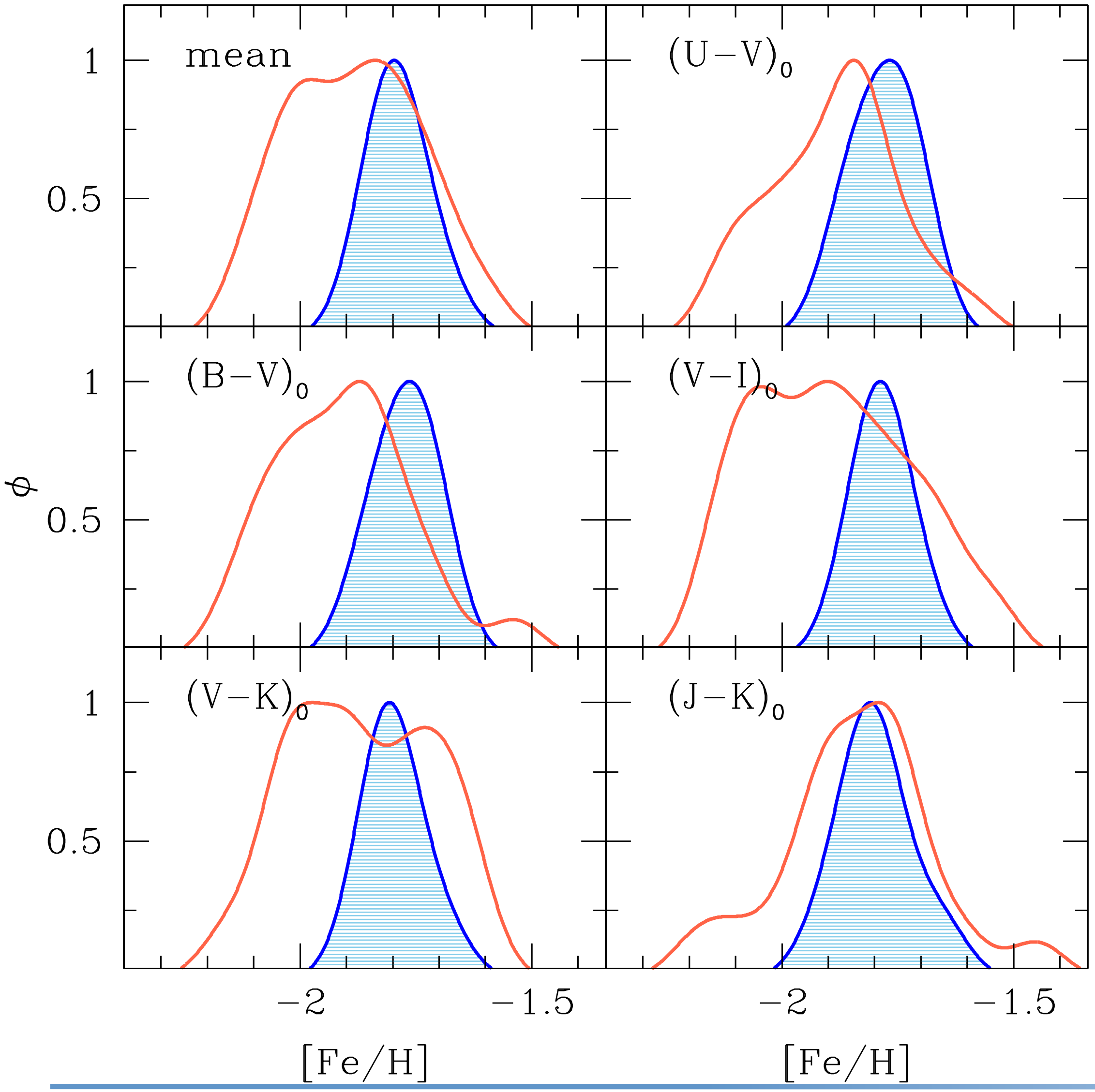
Spectroscopic logg | **Photometric logg**

Mucciarelli et al. , submitted



The case of M22

Temperatures from different broad-band colors



The case of M22

M22 is mono-metallic !!!

arXiv.org > astro-ph > arXiv:1507.01596

Search or Ar

Astrophysics > Solar and Stellar Astrophysics

A chemical trompe-l'œil: no iron spread in the globular cluster M22

A. Mucciarelli, E. Lapenna, D. Massari, E. Pancino, P. B. Stetson, F. R. Ferraro, B. Lanzoni, C. Lardo

(Submitted on 6 Jul 2015)

We present the analysis of high-resolution spectra obtained with UVES and UVES-FLAMES at the Very Large Telescope of 17 giants in the globular cluster M22, a stellar system suspected to have an intrinsic spread in the iron abundance. We find that when surface gravities are derived spectroscopically (by imposing to obtain the same iron abundance from FeI and FeII lines) the [Fe/H] distribution spans ~0.5 dex, according to previous analyses. However, the gravities obtained in this way correspond to unrealistic low stellar masses (0.1-0.5 Msun) for most of the surveyed giants. Instead, when photometric gravities are adopted, the [FeII/H] distribution shows no evidence of spread at variance with the [FeI/H] distribution. This difference has been recently observed in other clusters and could be due to non-local thermodynamical equilibrium effects driven by over-ionization mechanisms, that mainly affect the neutral species (thus providing lower [FeI/H]) but leave [FeII/H] unaltered. We confirm that the s-process elements show significant star-to-star variations and their abundances appear to be correlated with the difference between [FeI/H] and [FeII/H]. This puzzling finding suggests that the peculiar chemical composition of some cluster stars may be related to effects able to spuriously decrease [FeI/H]. We conclude that M22 is a globular cluster with no evidence of intrinsic iron spread, ruling out that it has retained the supernovae ejecta in its gravitational potential well.

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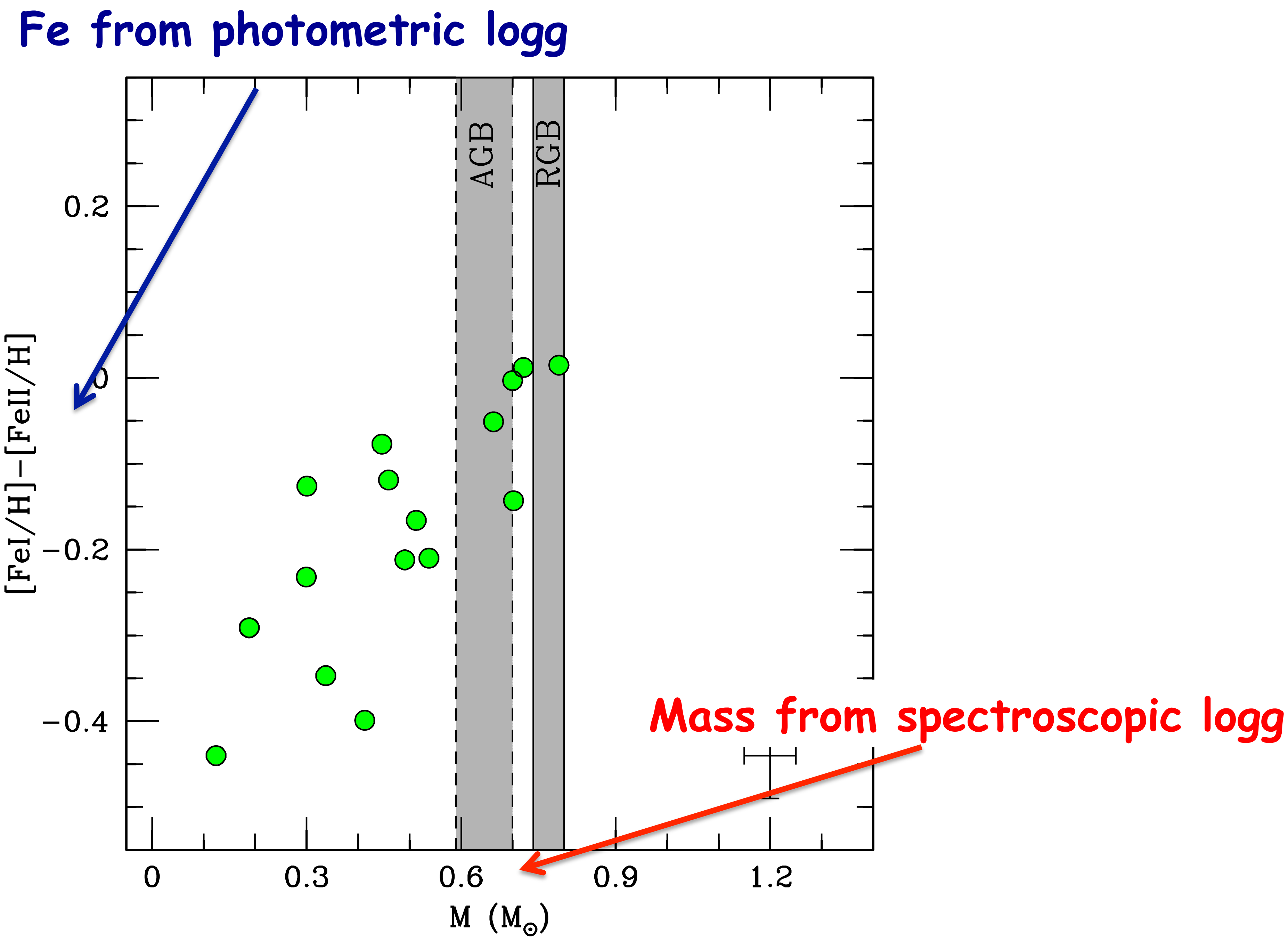
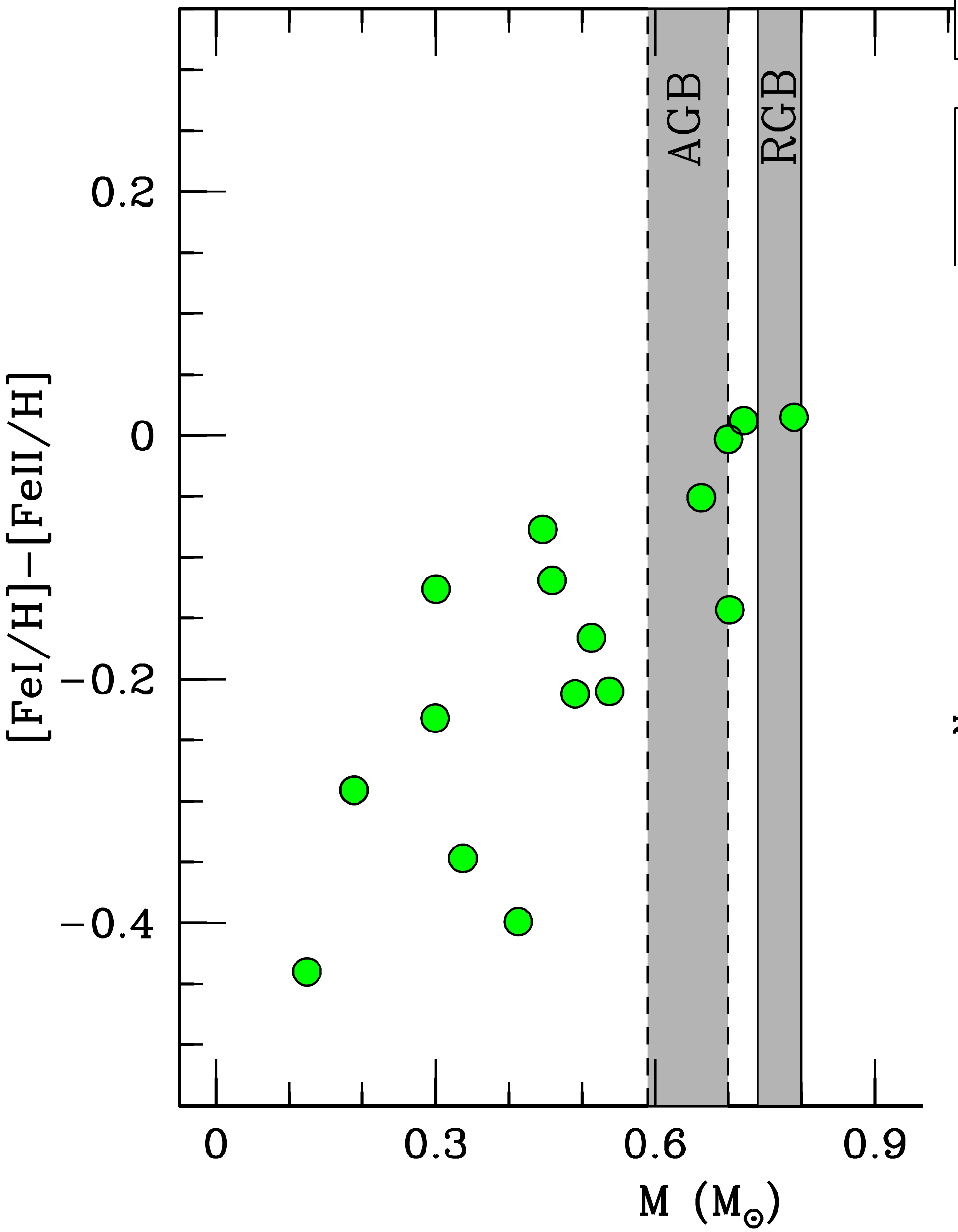
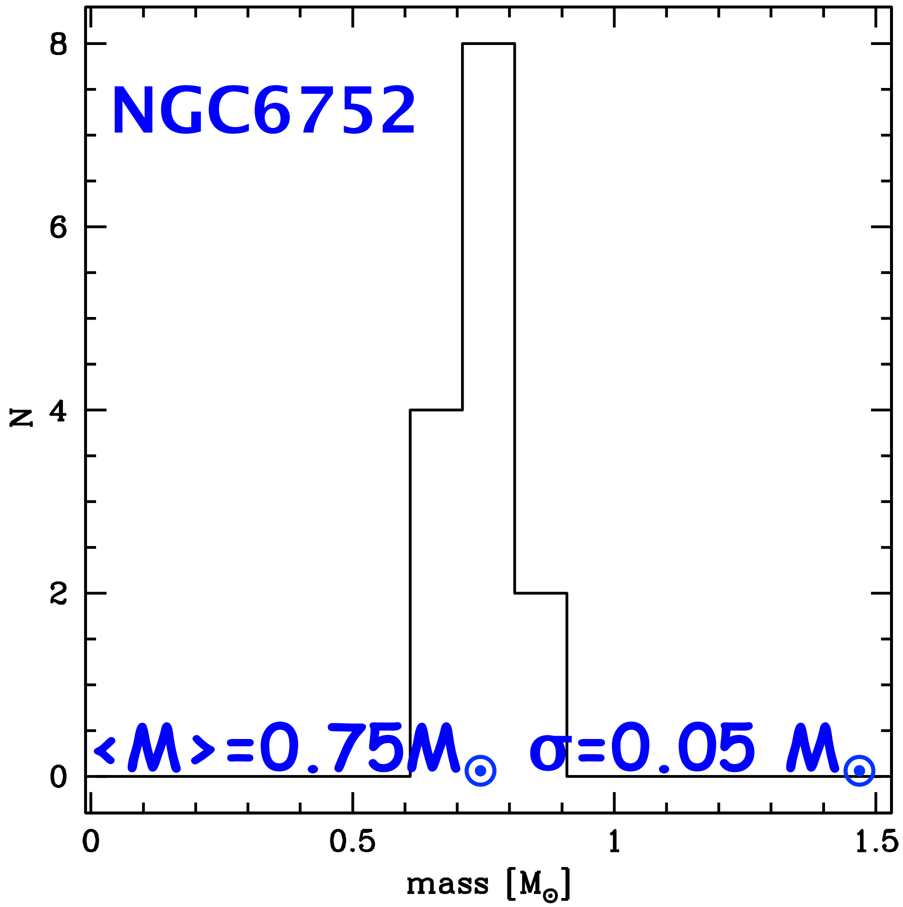
Subjects: **Solar and Stellar Astrophysics (astro-ph.SR)**; Astrophysics of Galaxies (astro-ph.GA)
Cite as: arXiv:1507.01596 **[astro-ph.SR]**
(or **arXiv:1507.01596v1 [astro-ph.SR]** for this version)


Fe from photometric logg
AGB
RGB
0.2
0
−0.2
−0.4
[FeI/H]−[FeII/H]
0
0.3
0.6
0.9
1.2
M (M⊙)
Mass from spectroscopic logg

The spectroscopic gravities imply unreliable stellar masses

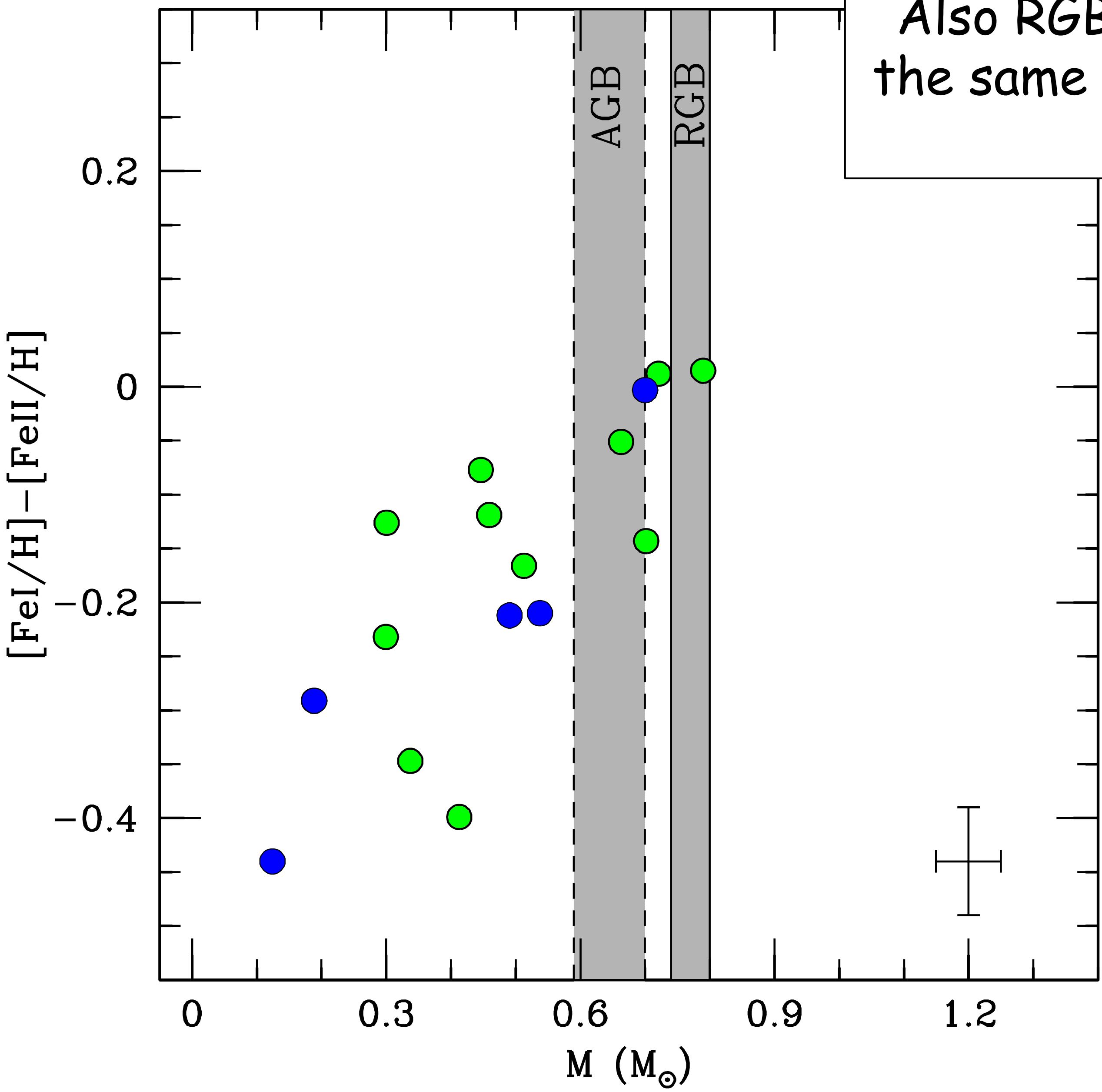
Masses from ~0.1 to ~0.8 $M_\odot$
<M> = 0.46$M_\odot$ σ=0.2 $M_\odot$

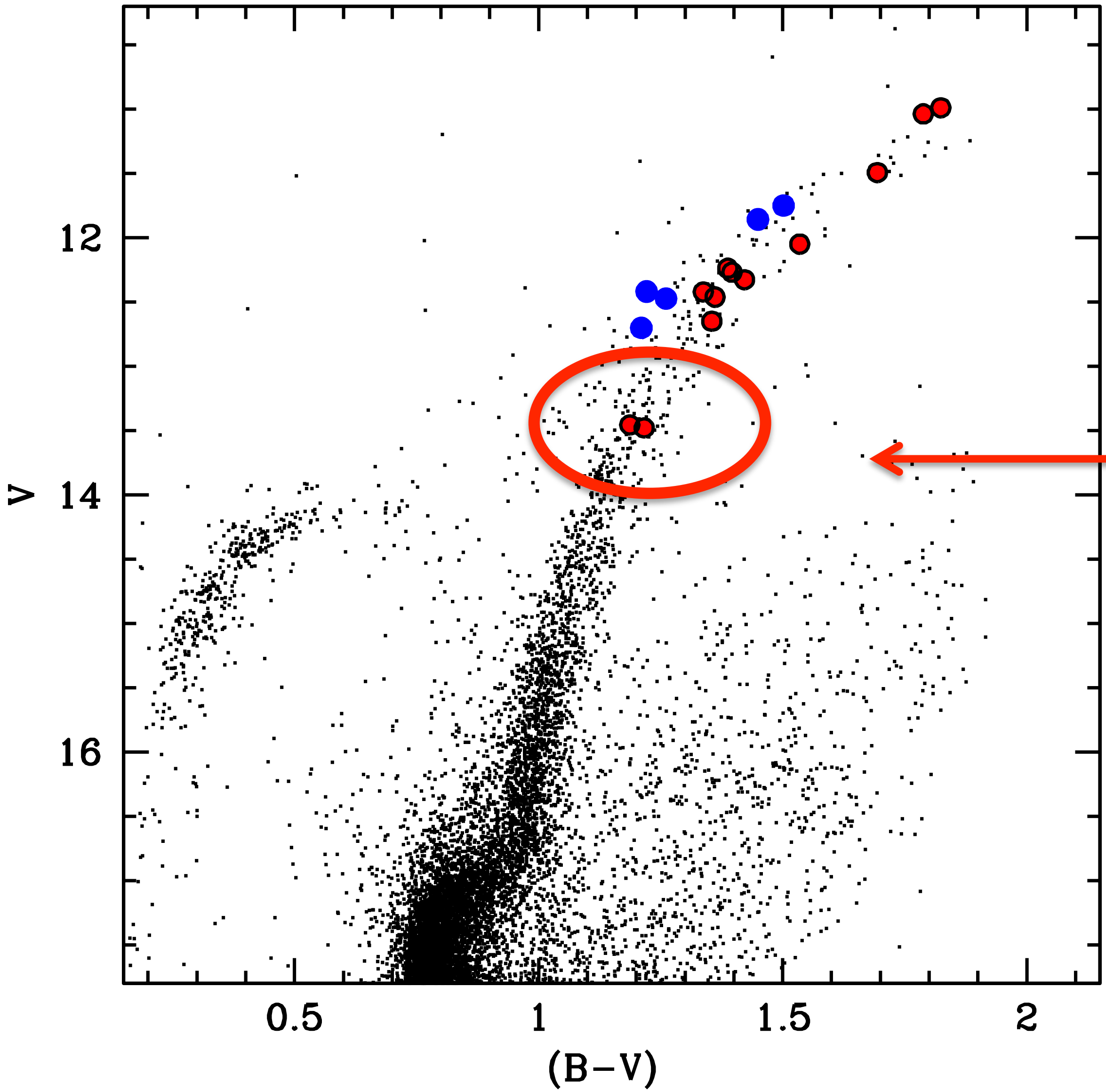




ACHTUNG !!!

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



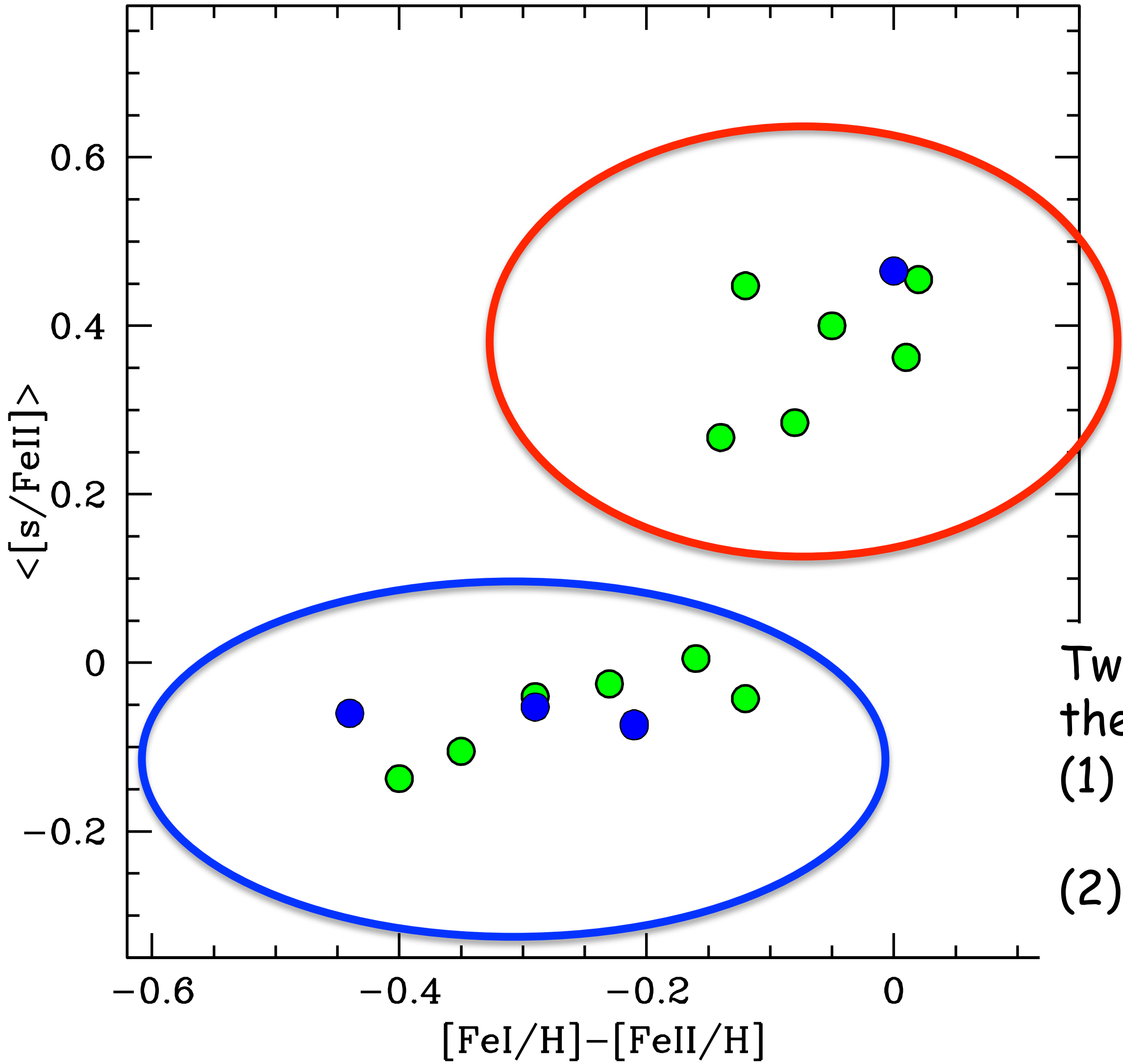


2 RGB stars

#221 [FeI/H]=-2.00
[FeII/H]=-1.71

#224 [FeI/H]=-1.88
[FeII/H]=-1.74

A normal globular cluster?   NO !!!



Two groups of stars with the same [FeII/H]:

(1) Low [FeI/H] (NLTE?) + normal s-process (4 AGB)

(2) Normal[FeI/H] + enhanced s-process (1 AGB)

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

Conclusions

- In AGB stars FeI lines provide systematically low abundances
- A working hypothesis: NLTE effects in AGB 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?)

The End