Chemical enrichment mechanisms in Omega Centauri: clues from neutron-capture elements

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"A Simple Stellar Population is defined as an assembly of coeval, initially chemically homogeneous, single stars ..
Four main parameters are required to describe a SSP, namely its age, composition (Y,Z), and the initial mass function
..**In nature the best example of SSPs are stellar clusters"** (Renzini & Buzzoni 1986).

THIS TRADITIONAL PERSPECTIVE IS NOW PROVEN

TO BE TOO SEMPLISTIC

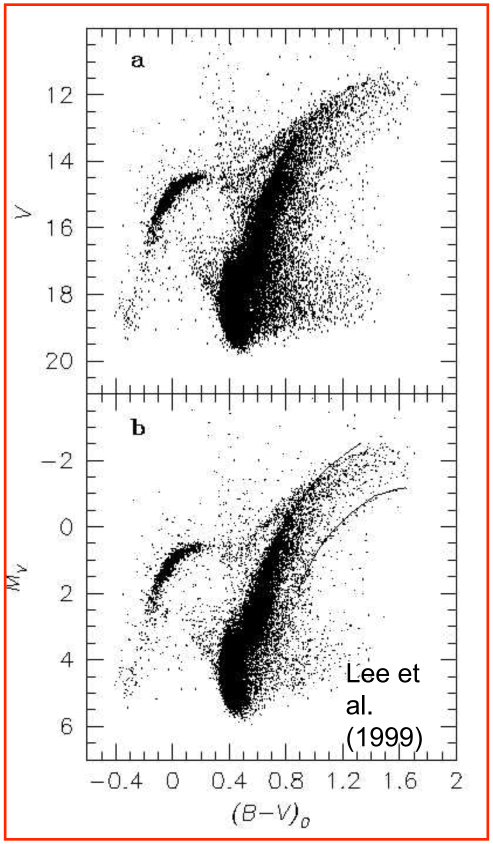
Photometry

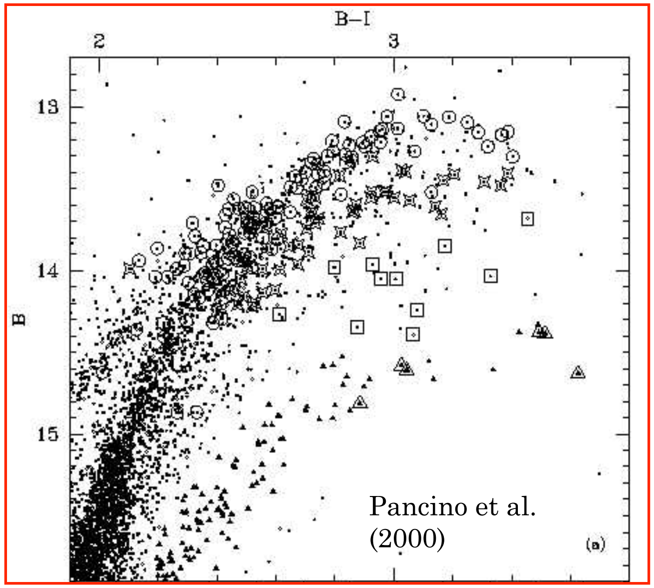
Spectroscopy

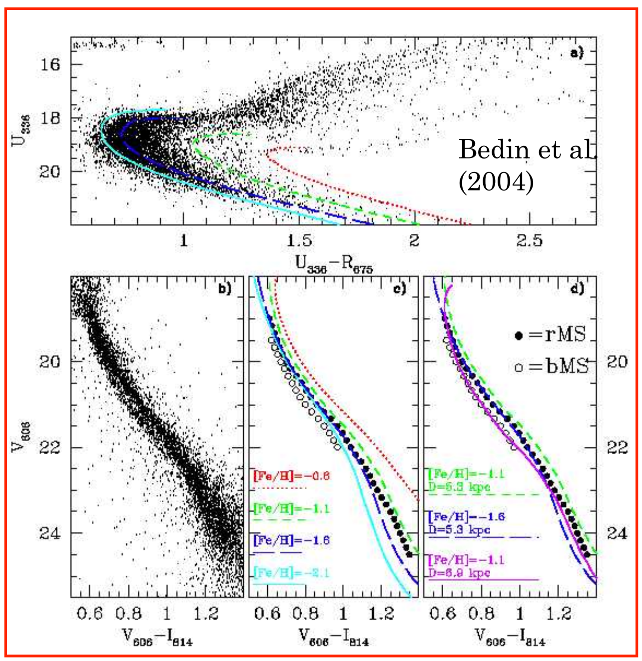
Globular Clusters ARE NOT Simple Stellar Populations

Photometry

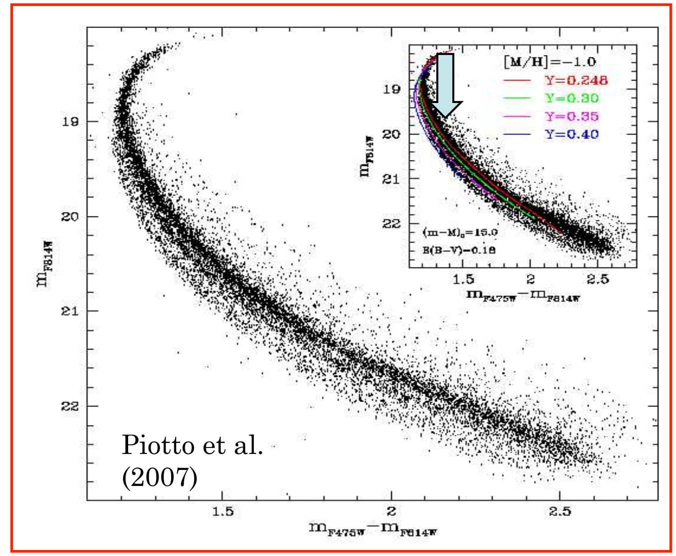
ω Cen



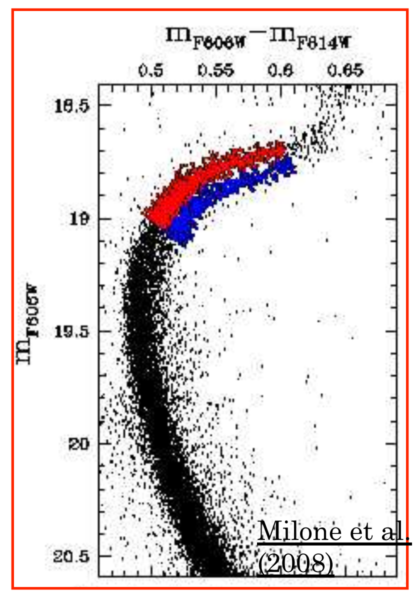




NGC 2808



NGC 1851

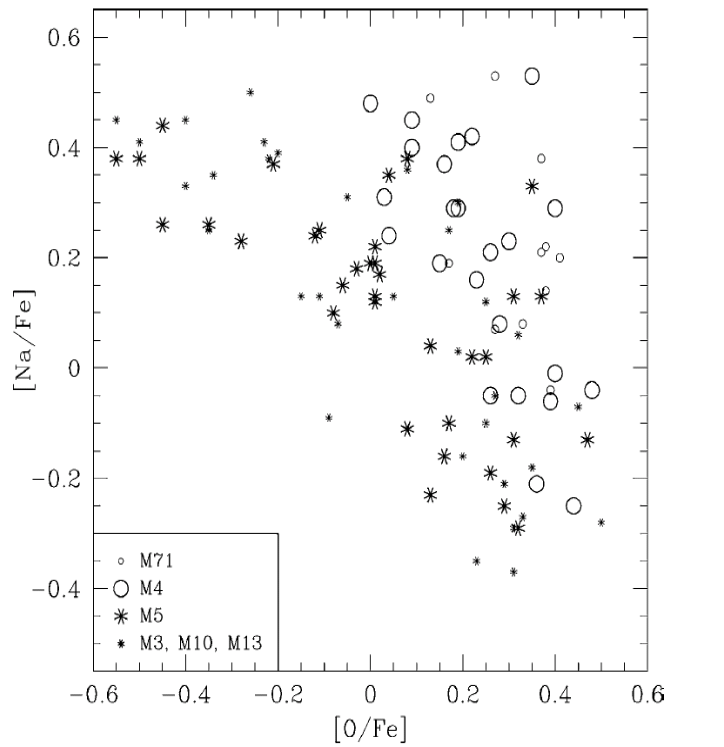


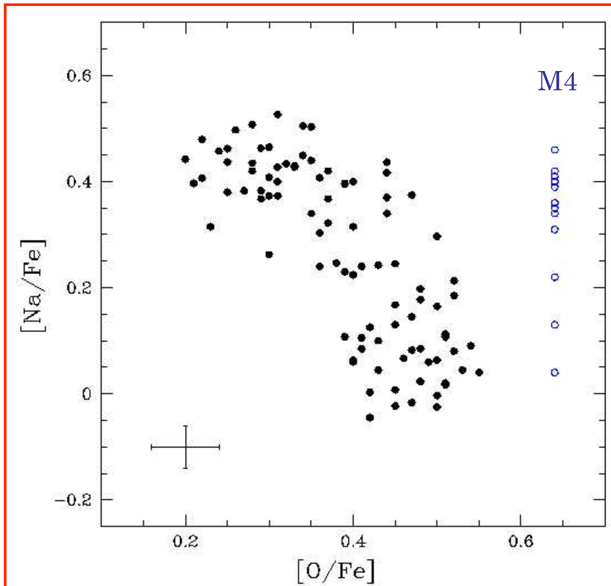
Since ’70s anti-correlations between light elements (C, N, O, Na, Mg, Al) the abundances of C, O, Mg are depleted where those of N, Na, Al are enhanced

Spectroscopy

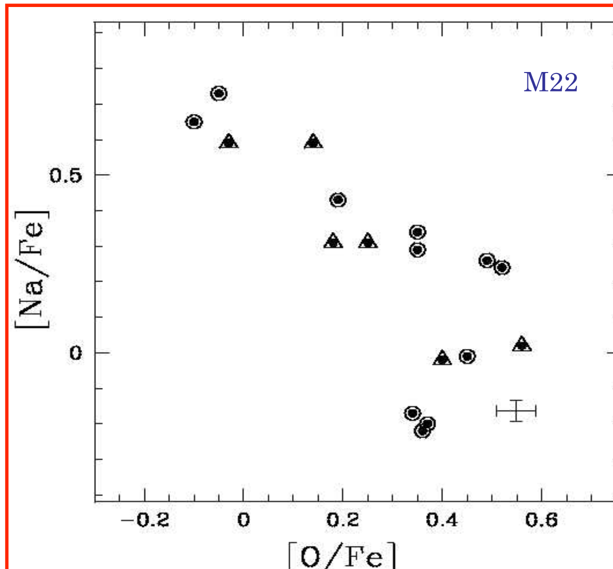
Cohen (1978); Peterson (1980); Norris (1981)

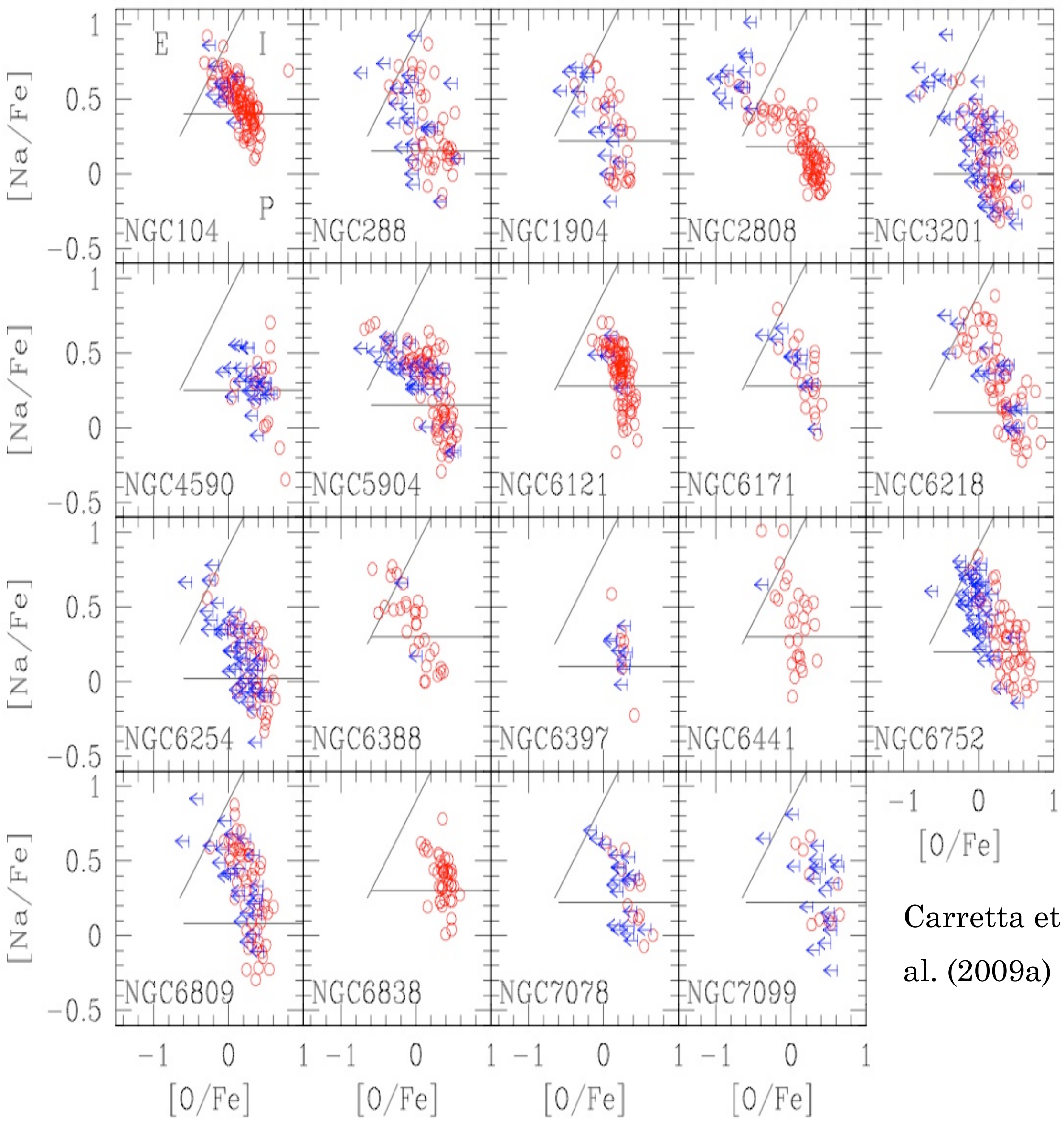
Lick-Texas group (from Ivans et al. 2001)





Marino et al. (2008, 2009)





Carretta et al. (2009a)

P=primordial FG
(share the same chemical compositon of field stars with same [Fe/H])

I=Intermediate SG

E=Extreme SG

(high Na, low O)

All the GCs show the Na-O anti-correlation

→ the second generation is always PRESENT

A PREVIOUS GENERATION of stars which synthesized in their interiors p-capture elements are RESPONSIBLE for these chemical signatures in GC stars

⇩

HOT hydrogen burning, where the ON, NeNa, and MgAl chains are operating - the ON reduces O, the NeNa increases Na (T ~ 30 million K), while the MgAl produces Al (T~65 million K)

Still debated……

- IM-AGB stars (4 – 8 M☉) experiencing Hot Bottom Burning (e.g., Ventura+ 2001)
- Winds of Fast Rotating Massive Stars (e.g., Decressin+ 2007)

✓GCs are homogeneous concerning Fe-peak and the heavy alpha-elements (e.g. Ca, Ti)

✓Light element variations (CH-CN, O-Na, Mg-Al)

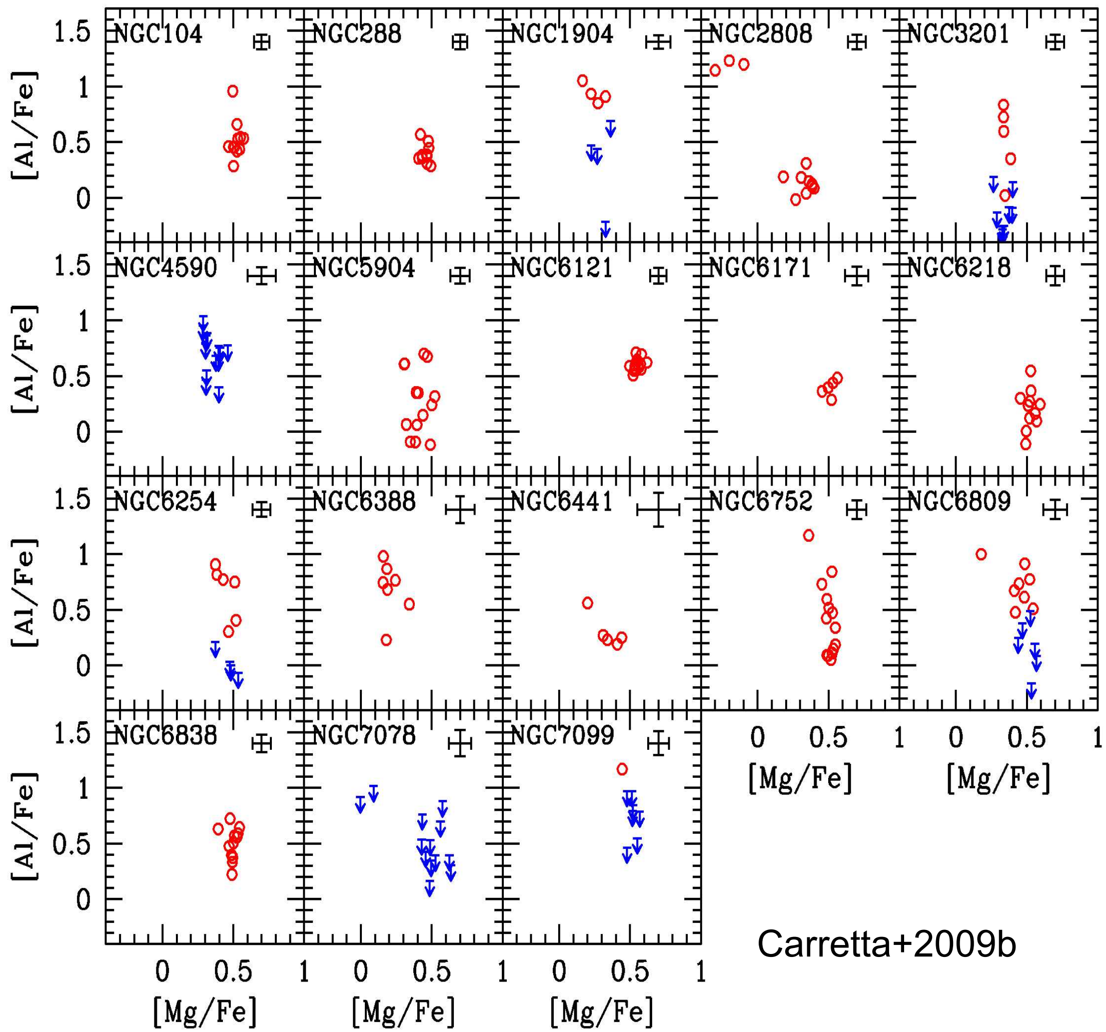
✓Heavy elements (Z>30) →

little star-to-star variation within GCs (Armosky+ 1994; James+ 2004)

Analysing a sample of ~1000 RGB GC stars (in 15 GCs) we found that [Ba/Fe] does not significantly vary (D'Orazi+ 2010)

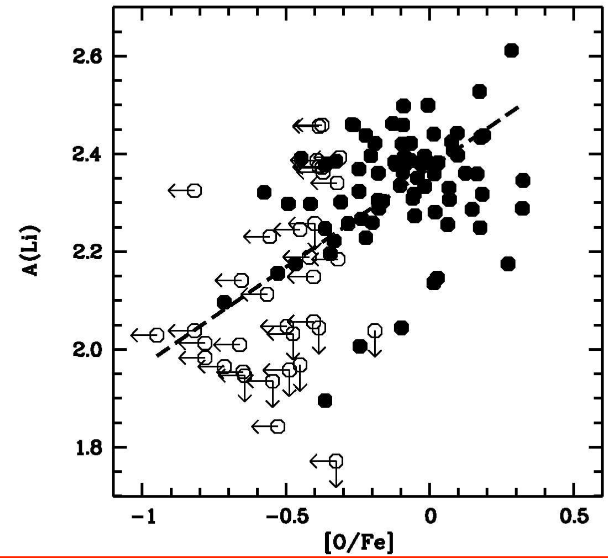
see Roederer (2011) for variation in r-process elements

A "typical" GC: NGC 6752



Carretta+2009b

Shen+2010



No variation in [Fe/H] +

Heavy elements

O-Na + Mg-Al anti-correlation

Li-O correlation (but the slope is not one)

However…..

NGC 7078 (M15) → variation in r-process elements

δ[Eu/Fe]~0.5 dex (Sneden+1997; Sobeck+2011)

NGC 6656 (M22) → δ[Fe/H]~0.15 dex positively correlated

with δ[Ba,Y,Zr/Fe]~0.4 dex (e.g., Marino+2009)

NGC 1851 → variation in δ[Fe/H] from 0.06 to 0.25

(Carretta+2010a; Yong & Grundahl 2008)

δ[Ba/Fe] from ~0.6 dex to > 1 dex

(Carretta+2011; Villanova+2011; Yong & Grundahl 2008)

NGC 6715 (M54, Sgr dSph) → δ[Fe/H] = 0.19 dex (Carretta+ 2010b)

NGC 5139 (Omega Centauri)

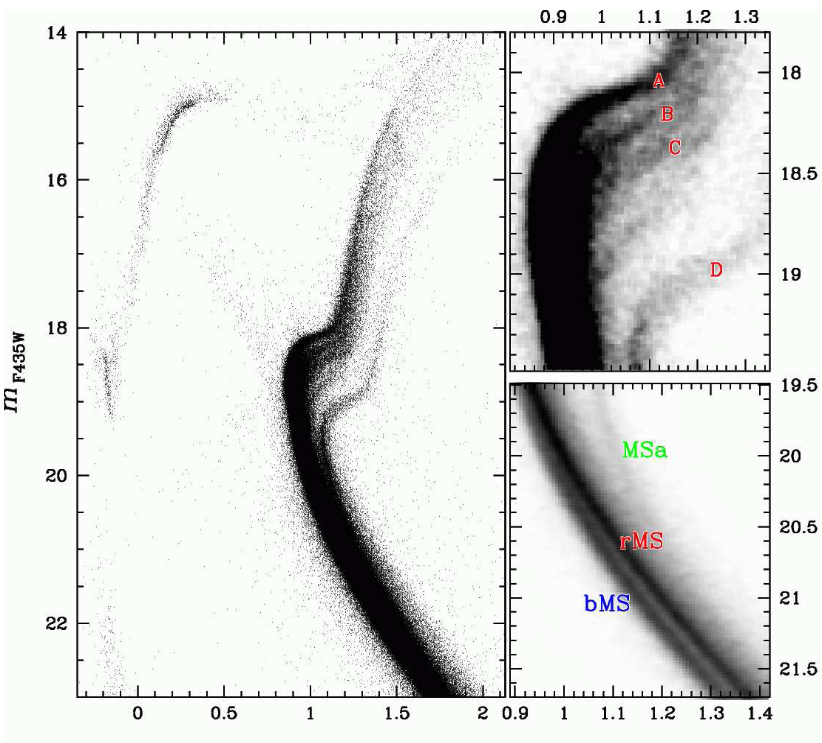
The most massive GC of our Galaxy: (~2.5x10[6] M⊙, van de Ven+2006)

Photometric investigations:

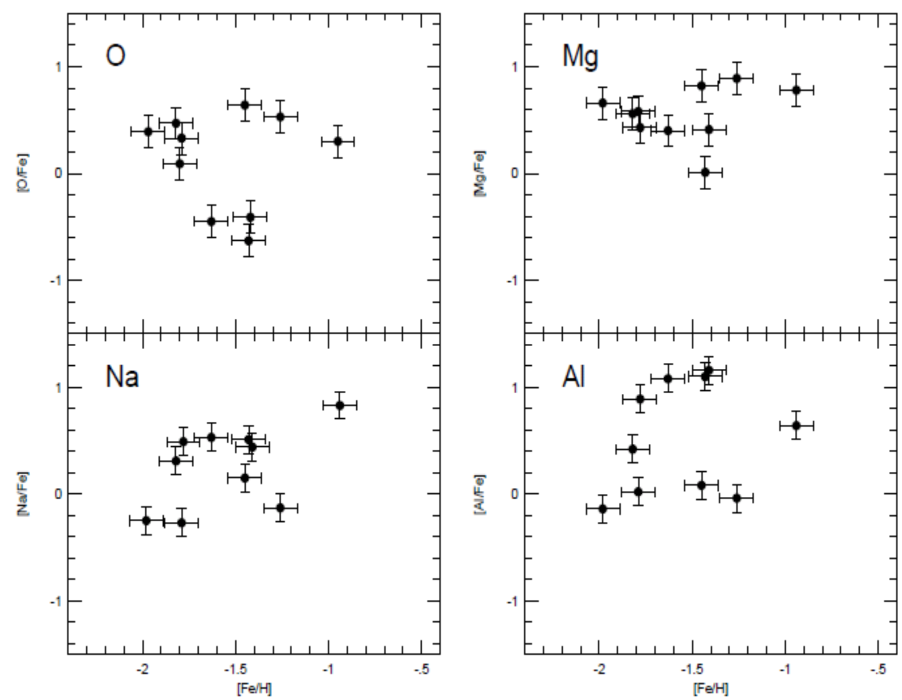
(e.g. Wooleey 1966; Anderson 1997;Pancino+2000; Bedin +2004; Sollima+2005)

High-resolution spectroscopic study:

Norris & Da Costa (1995); Smith +(2000); Johnson & Pilachowski (2010); Marino+(2011)



Bellini+2010



Smith+2000

Johnson & Pilachowski (2010)

more than 800 RGB stars

1. [Fe/H] variation from ~-2 to ~-0.6

2. alpha-elements + Fe-peak match the SN II abundance pattern

3. Variation in O, Na, Al > 0.5 dex

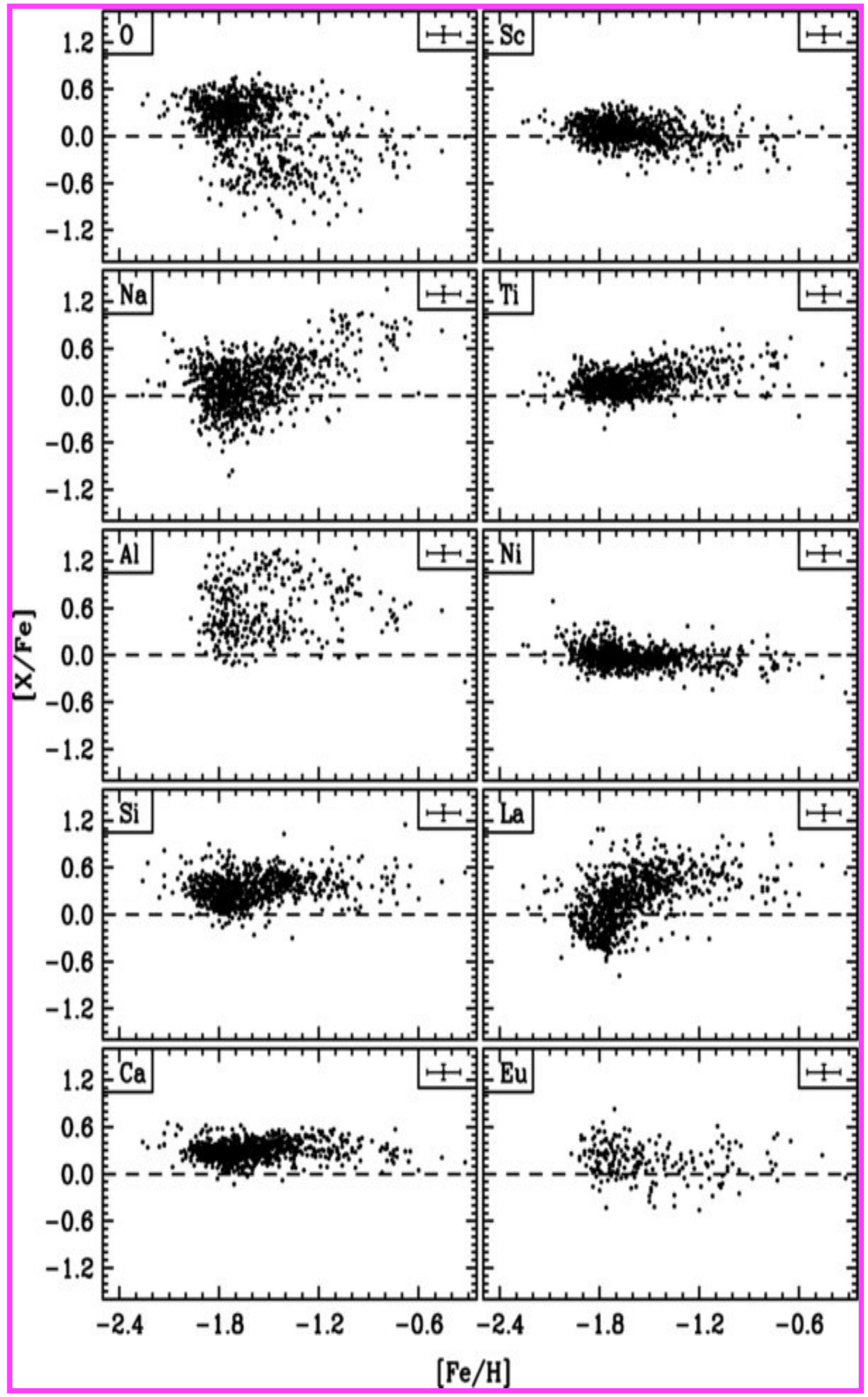
   (anti-correlated abundances, with the exception of the most metal-rich stars)

4. No significant contribution from SN Ia

5. Strong increase in [La/Fe] vs [Fe/H]

   (not accompained by similar trend for [Eu/Fe]

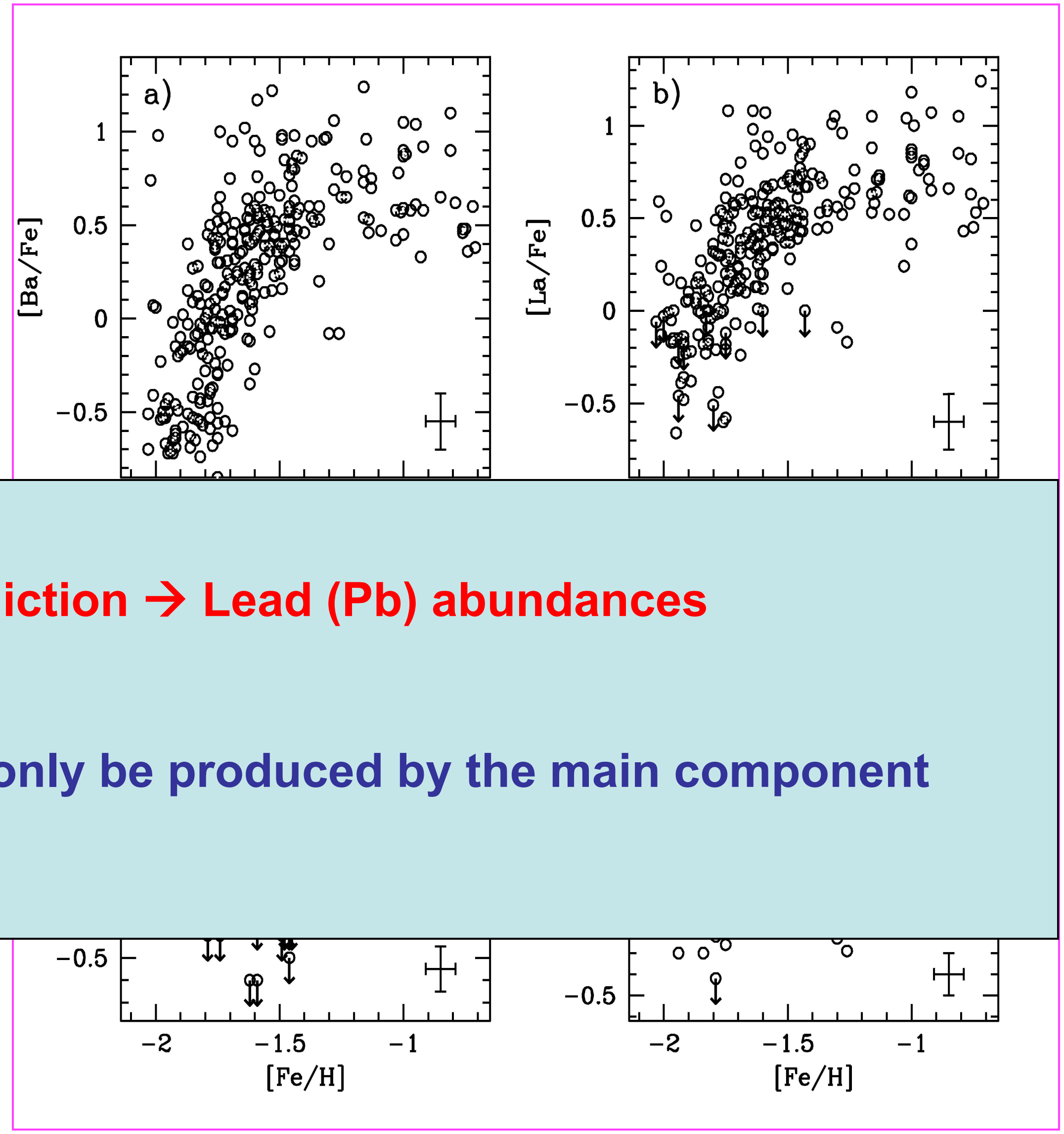
→ low-mass AGB contributions



Marino et al. (2011)   > 300 RGB stars

<u>*main* component</u>

(≈1-4 $M_{\odot}$ AGB) responsible for elements beyond Zr (A>90)



To test this prediction → Lead (Pb) abundances

In the s-process, Pb can only be produced by the main component

“The weak component at lower metallicity could produce heavier elements, up to Ba and La”

The sample

Table 1. Identification, photometry and adopted parameters for our program stars (see JP10).

Leiden	ROA	V	B−V	K	Teff (K)	logg	[Fe/H]	ξ (km s^{-1})
16015	213	12.127	1.122	9.210	4510	1.05	-1.92	2.00
37247	238	12.430	1.163	9.363	4385	1.05	-1.88	1.75
33011	159	11.879	1.337	8.715	4305	0.80	-1.75	2.05
41039	256	12.251	1.230	9.190	4375	1.00	-1.73	1.95
46092	92	11.830	1.571	8.128	3990	0.45	-1.45	2.10
34029	243	12.107	1.452	8.719	4170	0.80	-1.28	1.90
44462	321	12.559	1.403	8.942	4040	0.90	-1.18	1.65
60066	2118	13.086	1.253	10.330	4640	1.75	-0.98	1.55
60073	211	12.266	1.613	8.525	3985	0.75	-0.82	2.00
34180	517	13.030	1.503	9.329	4015	1.05	-0.79	1.95
48323	500	13.081	1.461	9.273	3945	0.65	-0.73	2.00
54022	2594	13.360	1.412	9.910	4135	1.15	-0.46	1.80

D'Orazi+ (2011, subm.to A&A)

12 RGB stars

Spanning a range in metallicity from

[Fe/H]=-1.92

to [Fe/H]=-0.46

UVES@VLT spectra

(R~45,000)

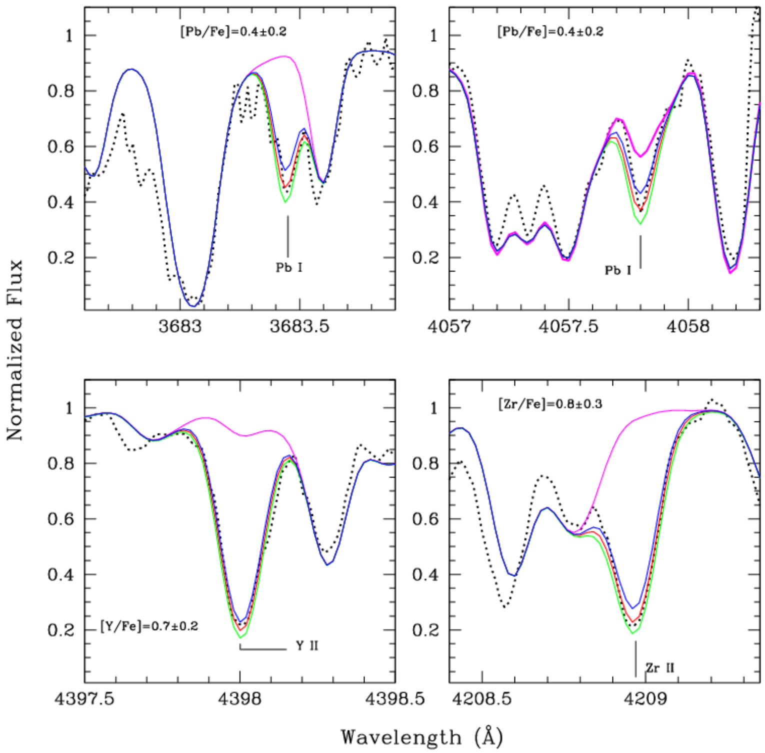
λ=3600 – 4600 Å

and for two stars

also λ=5400 – 8900 Å

Pb, Y, Zr, La, Ce, Eu, and the C+N+O sum

Analysis

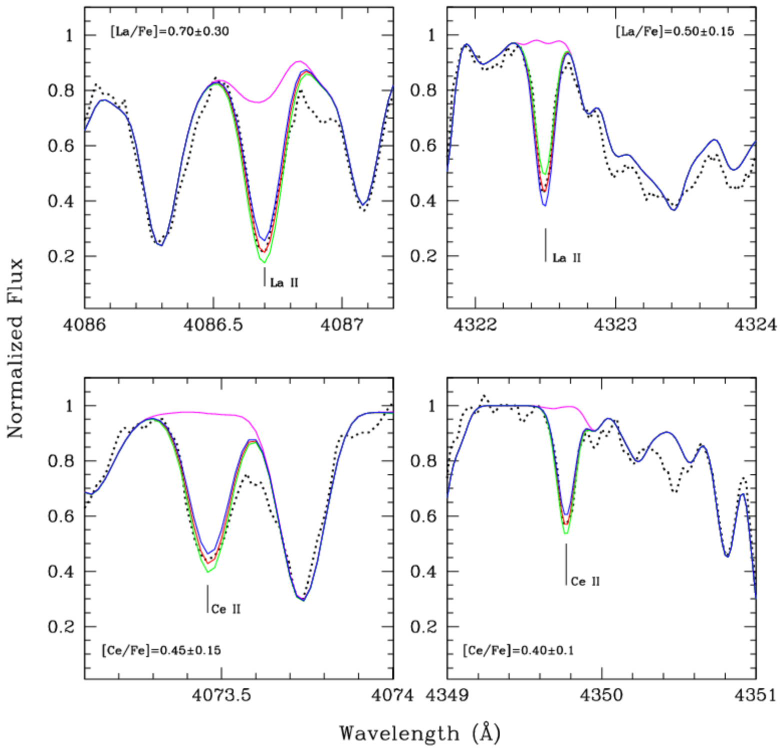


Pb I lines:3683 Å

4058 Å

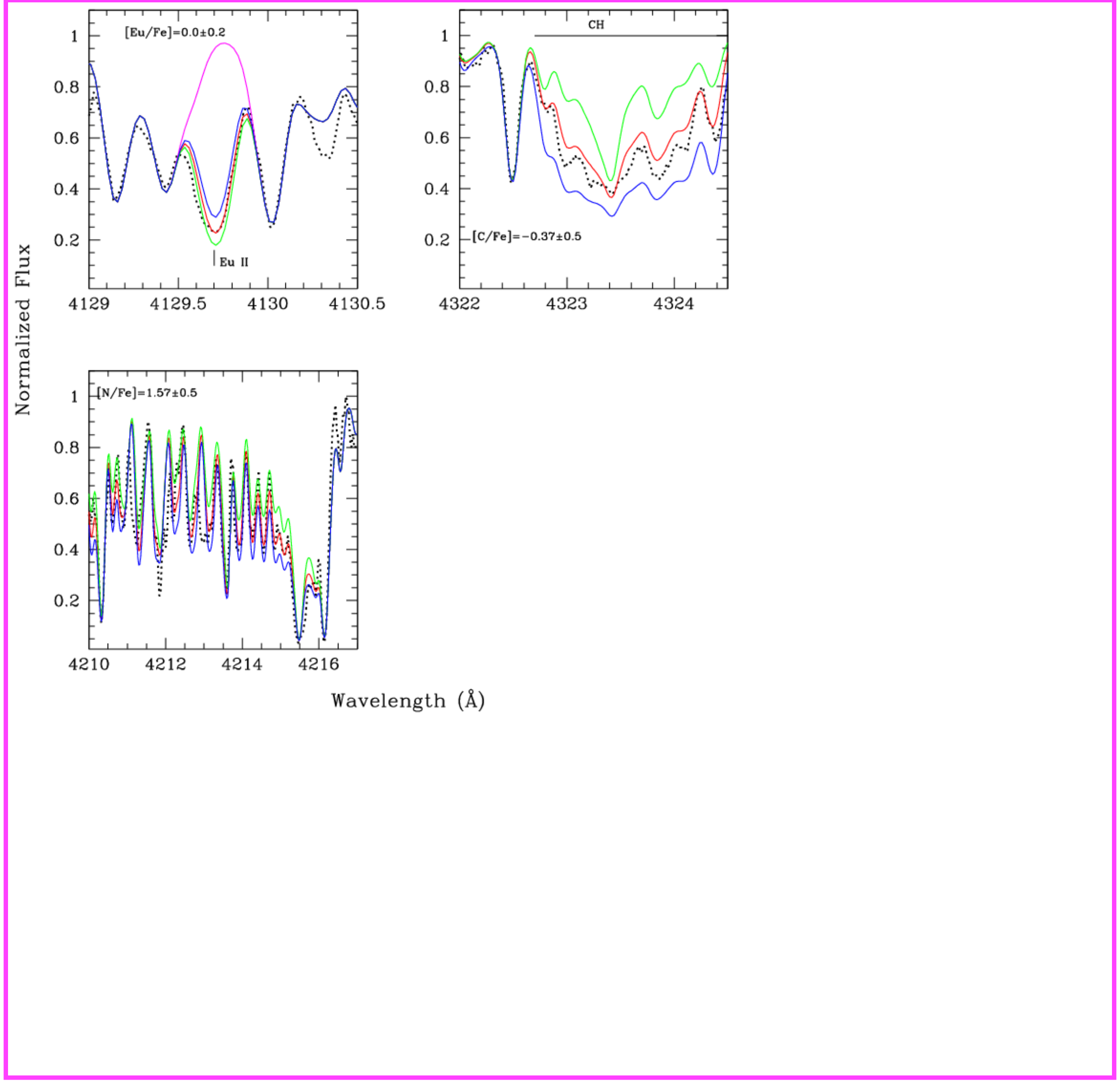
YII line 4398 Å

ZrII line 4208 Å



La II lines:4086 Å
4322 Å

Ce II lines: 4073 Å
4349 Å

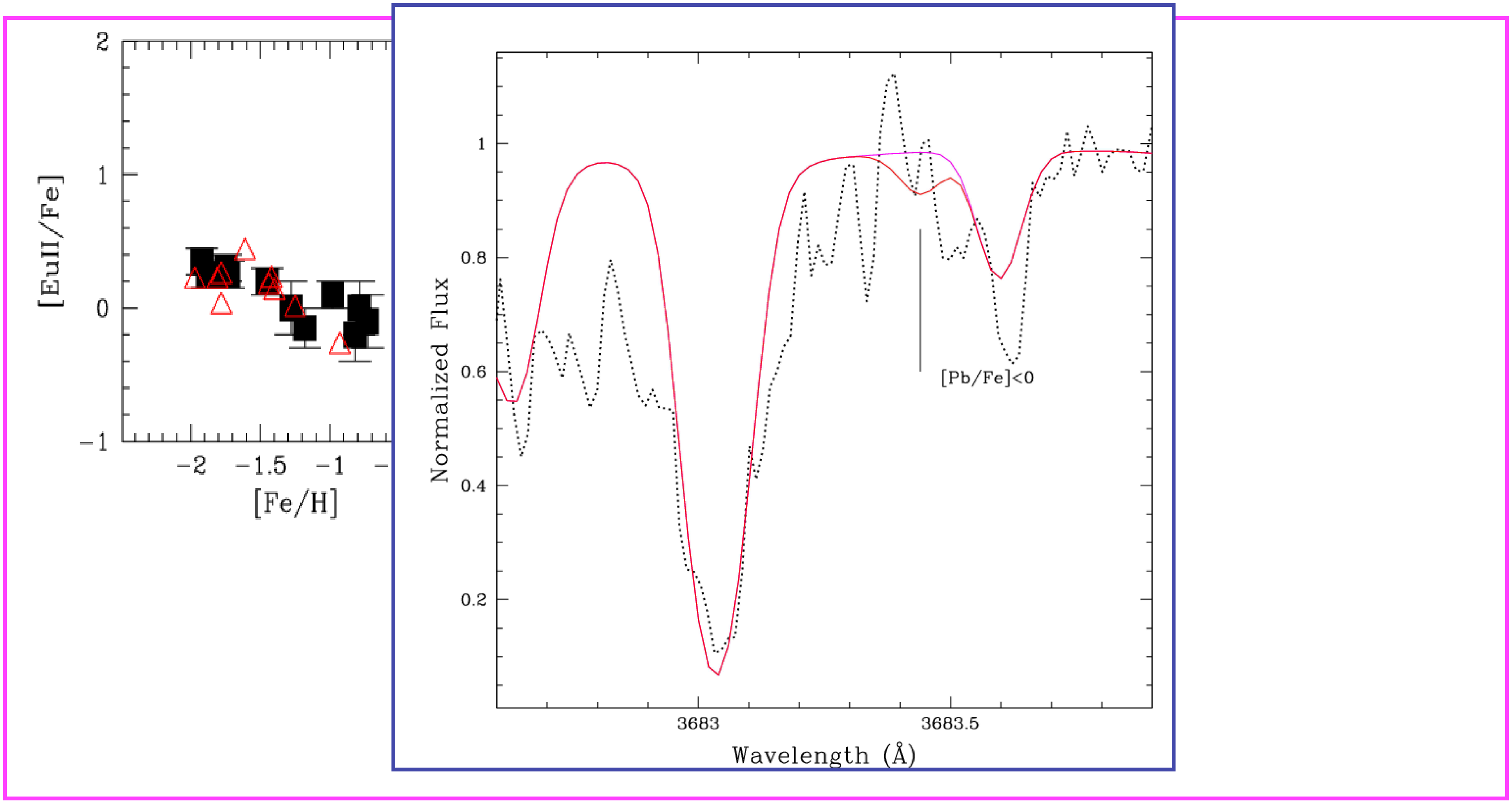


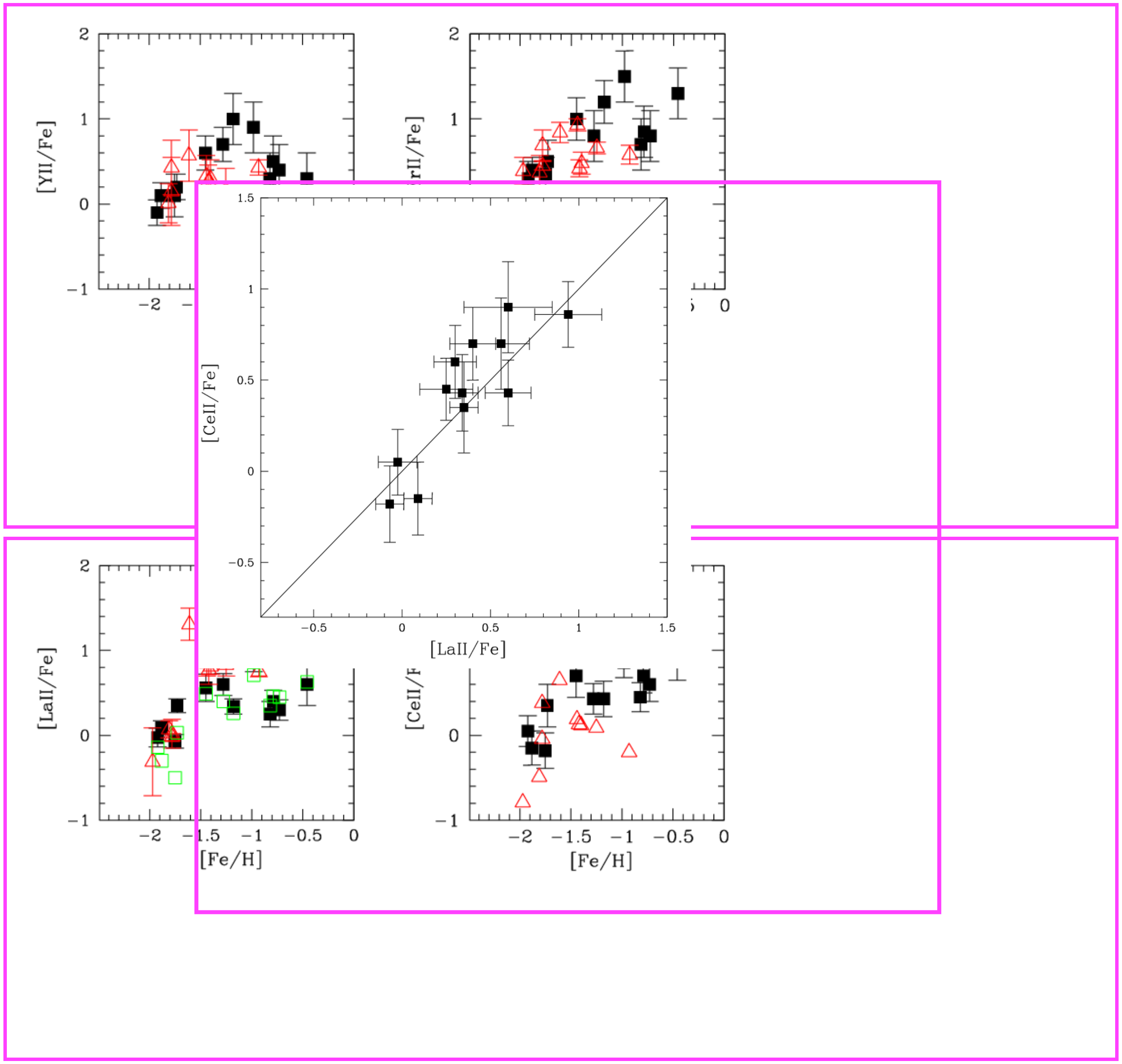
Eu II line :4129 Å

CH G-band at 4300 Å

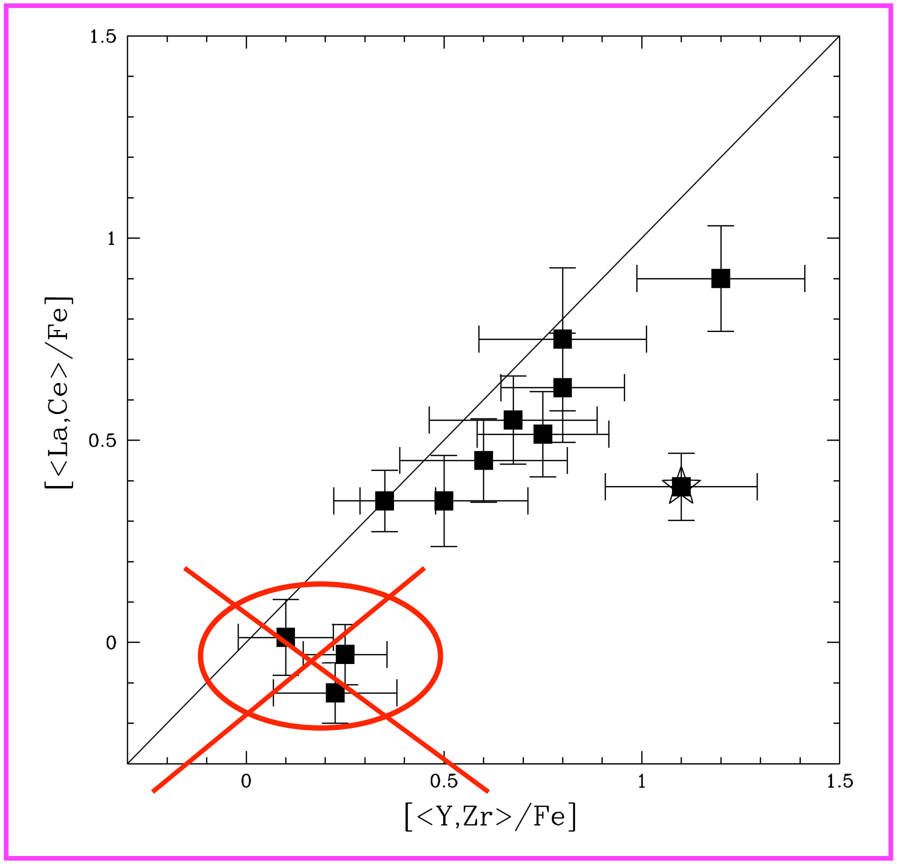
CN violet band at 4215 Å

We detected the hint for a Pb production occurring at [Fe/H]~-1.7 dex





[YII/Fe]
rII/Fe]
[CeII/Fe]
[LaII/Fe]
[LaII/Fe]
[CeII/F
[Fe/H]
[Fe/H]



At variance with Smith+(2000)

We found that the variation of light s-process

(first-peak) elements, i.e. Y, Zr

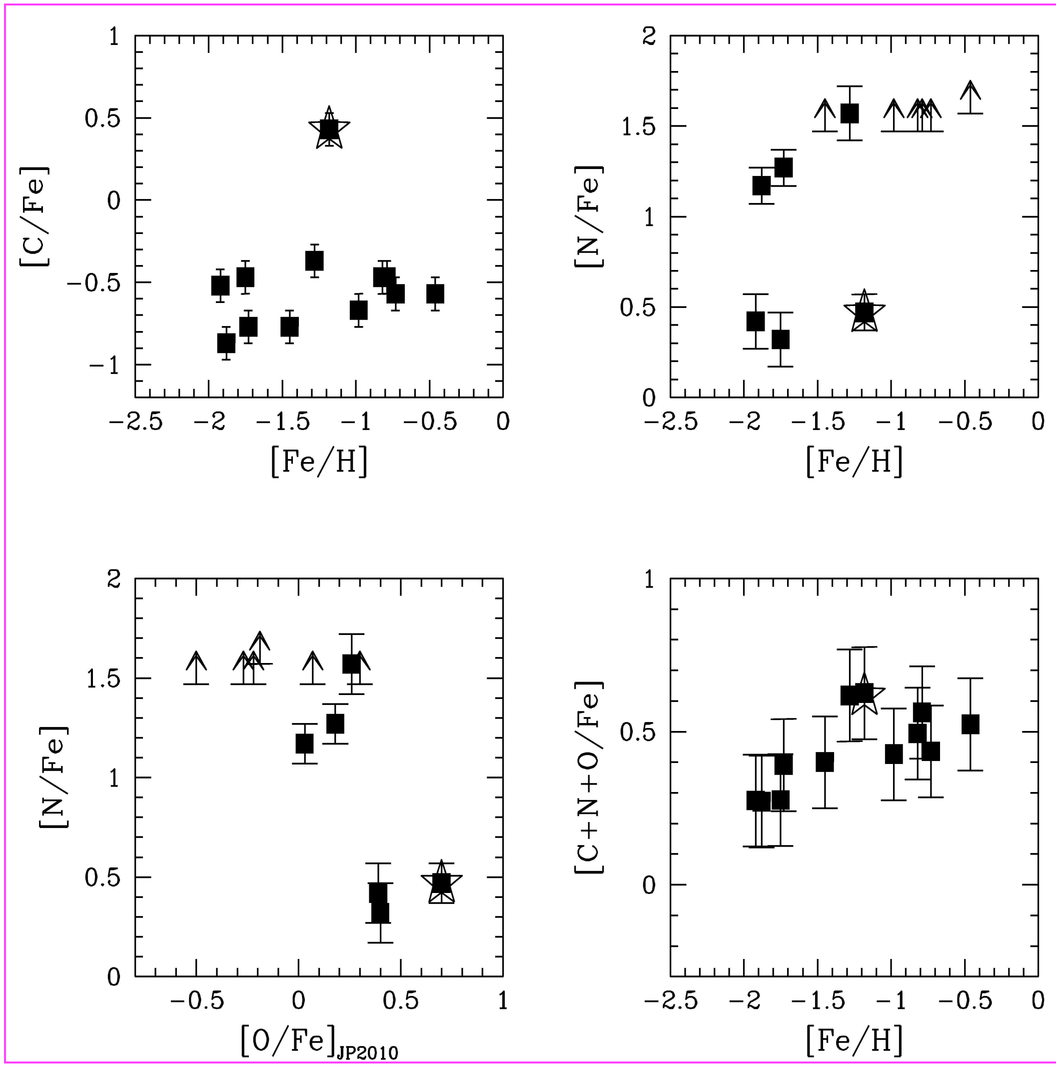
is LARGER than the one of

heavy (second-peak), here La, Ce.

We have to discard the most metal-poor stars, since they have a mostly r-process nucleosynthesis

Δ [<Y,Zr>/Fe]=0.7 dex
Δ[<La,Ce>/Fe]=0.5 dex

The C+N+O sum



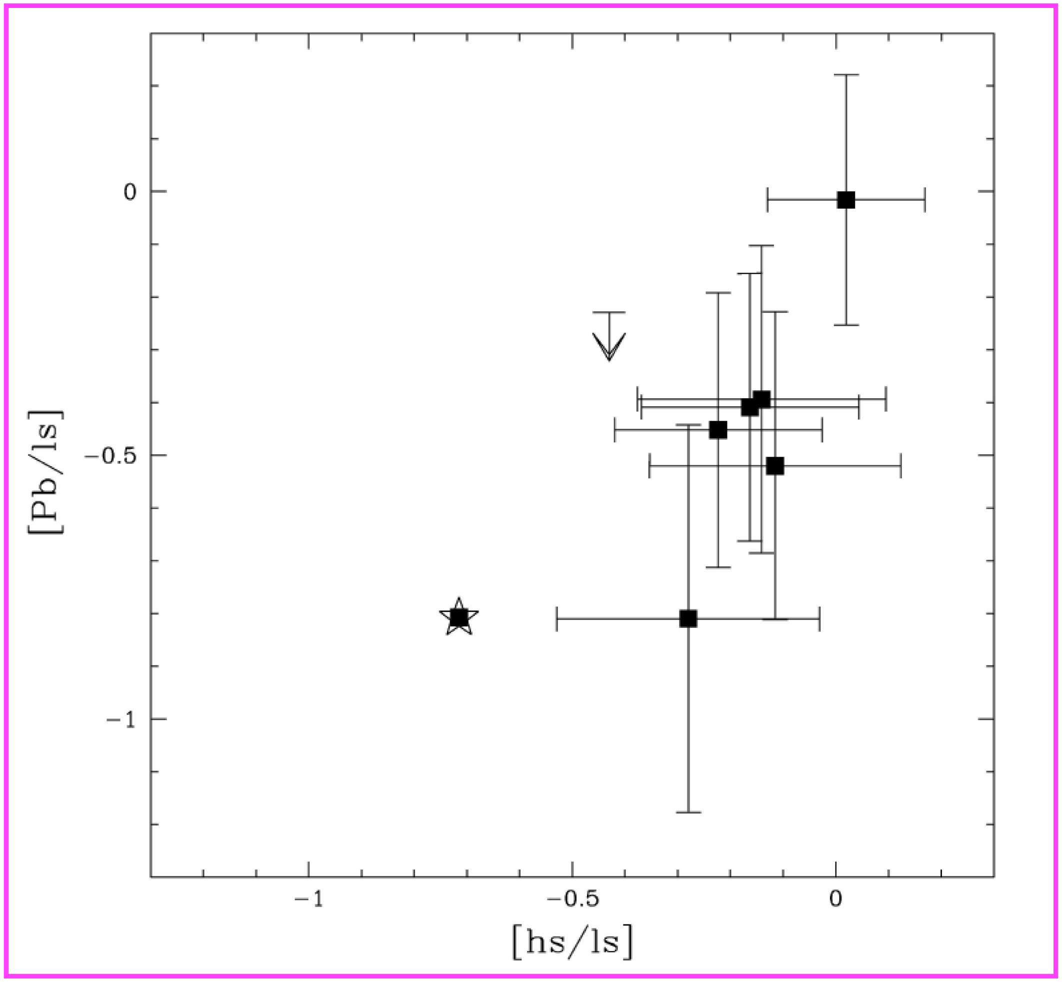
1. <[C/Fe]>=-0.51±0.10 (NDC95)

2. metal-poor stars are both N-rich and N-poor, while metal-rich ones are ONLY N-rich

N-O anti-correlation

except for the most metal-rich

The C+N+O sum moderately raises up to [Fe/H] ~ -1.5 dex and then remains CONSTANT



The [Pb/ls] ratio varies

more than the [hs/ls]

The Pb variation

rules out the weak

component as main

mechanism for s-process

element production:

In Omega Cen the main component is at work

~~*Weak component*~~ →

1) Pb production

2) [Cu/Fe] costant as a function of [Fe/H] (e.g., Cunha+ 2002)

3) Theoretical studies also argue

that at lower metallicities the weak component can not produce significant amounts of elements heavier than Zr

see Raiteri+ (1992); Pignatari & Gallino (2008)

We agree with the Smith's conclusion that low-mass AGB (main component) are responsible for the s-process element production in Omega Cen..

Intermediate-mass ... ss elements

(the same ... lg
responsibl
element pa

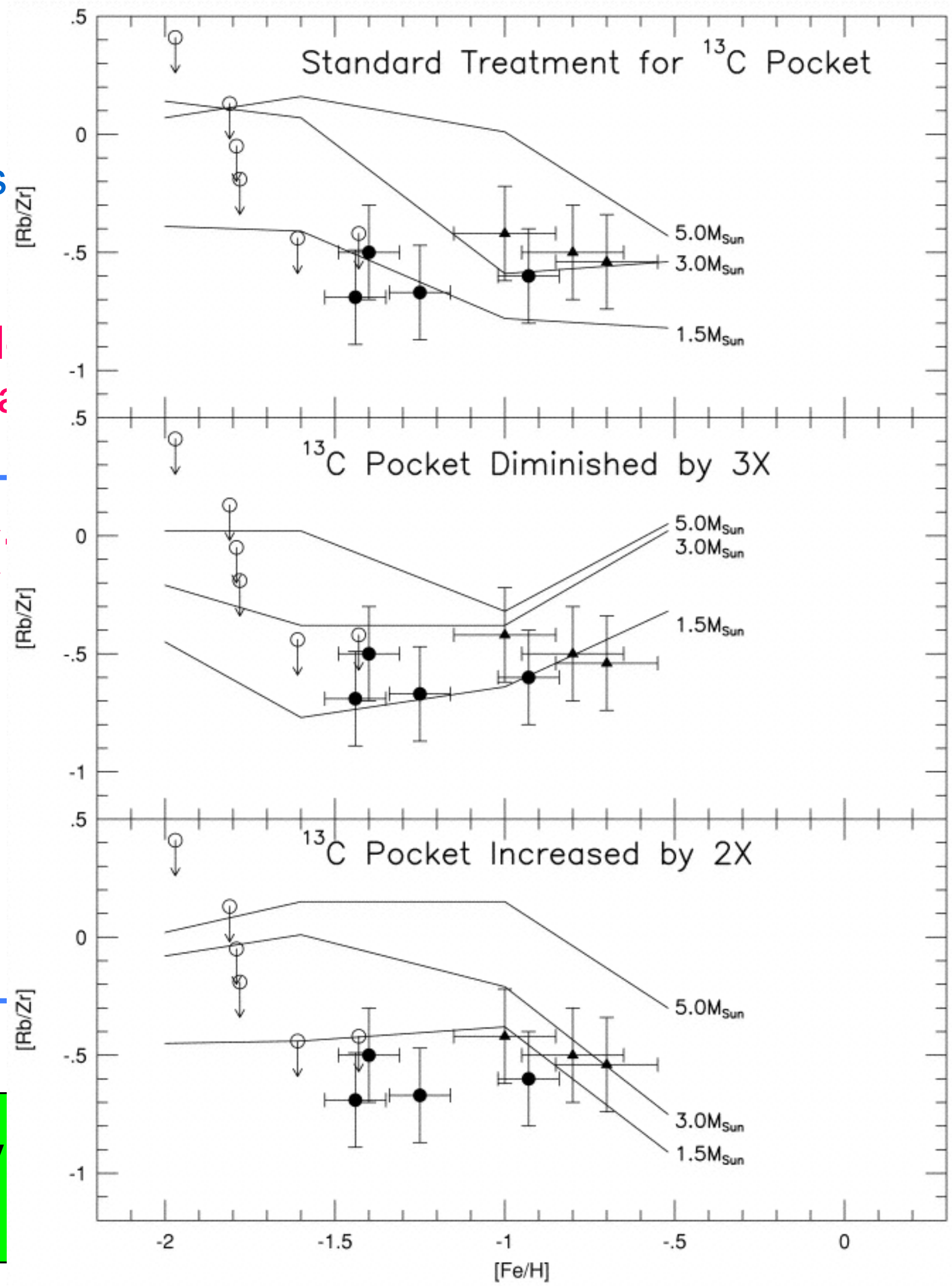
BUT: (... ess

) 2008)

Zr

+2006)

Only ... 800A)



However…..

Smith+(2000) concluded that ~ 1.5 Msun AGB model better reproduce the observed pattern

→ >1Gyr difference between the different stellar generations in Omega Cen

Our results:

- More production of light s-process elements with respect to the heavy ones
- Pb production but NOT as larger as the one of light s-process elements

→ neutron exposures quite small, few thermal pulses : LARGER MASS (!!!)

we suggest the main component is peculiar in this GC and slanted towards the higher mass, i.e. about 3.5/4 Msun.

⇨ Note also that the CNO sum slightly raises with metallicity ⇦

Drastic reduction in the age difference from >1 Gyr to several Myrs