Oxygen variations in Globular Clusters and the multiple population scenario

Valentina D'Orazi

INAF Padova
Dept. of Physics and Astronomy, Macquarie University
Monash Centre for Astrophysics, Monash University

Core team: Raffaele Gratton, Sara Lucatello (INAF Padova), Angela Bragaglia, Eugenio Carretta (INAF Bologna)

Colls.: Anna F. Marino (Max Planck Institute, Munchen) Chris Sneden (The University of Texas at Austin) Simon W. Campbell, Maria Lugaro, John Lattanzio, George Angelou (Monash University) Thomas Masseron (Universite de Brussels) Inese Ivans (University of Utah) Marco Pignatari (University of Basel)

"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).

Globular Clusters for many years considered as ideal

benchmarks for studying stellar evolution

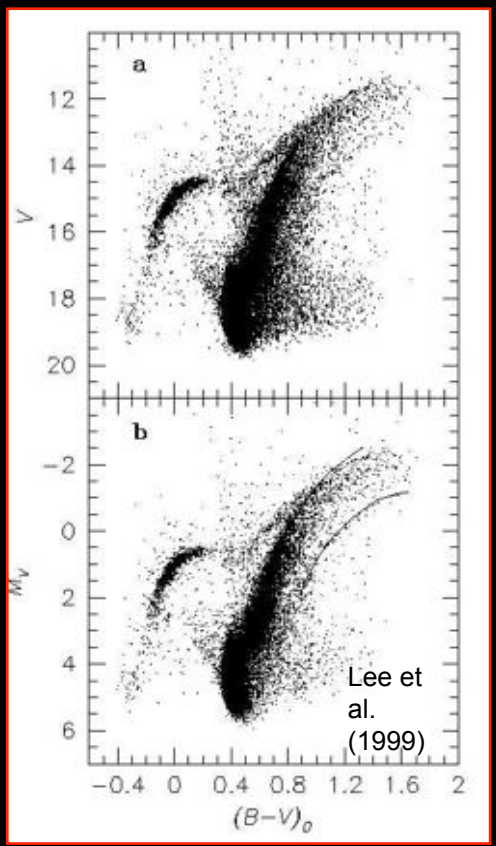
& synthesis population models

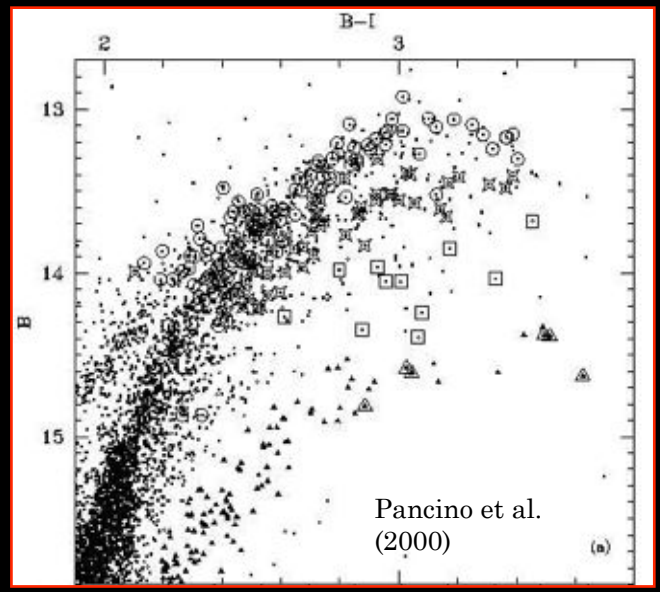
THIS TRADITIONAL PERSPECTIVE IS NOW PROVEN TO BE TOO SIMPLISTIC….

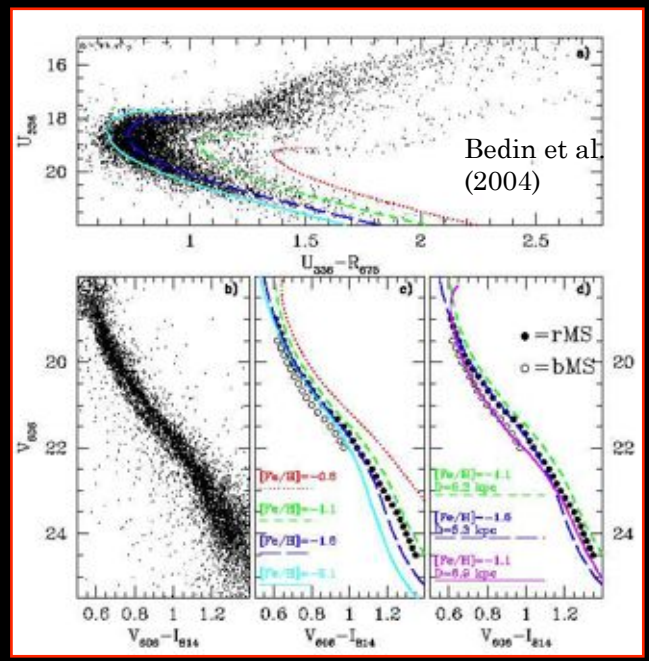
Globular Clusters ARE NOT Simple Stellar Populations

Photometry

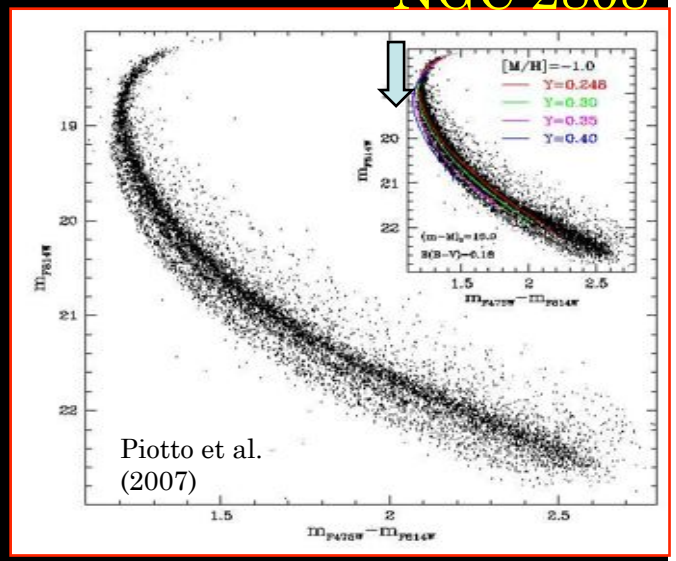
ω Cen

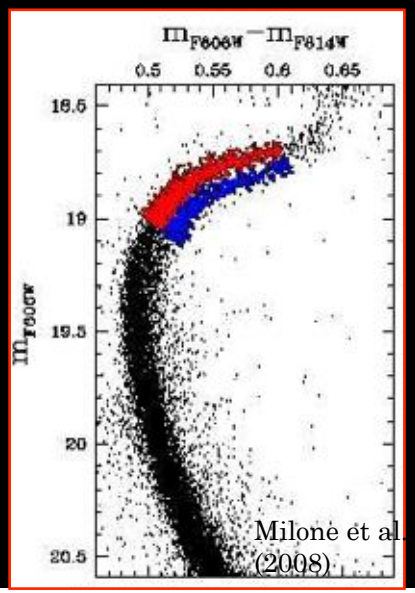






NGC 2808





NGC 1851

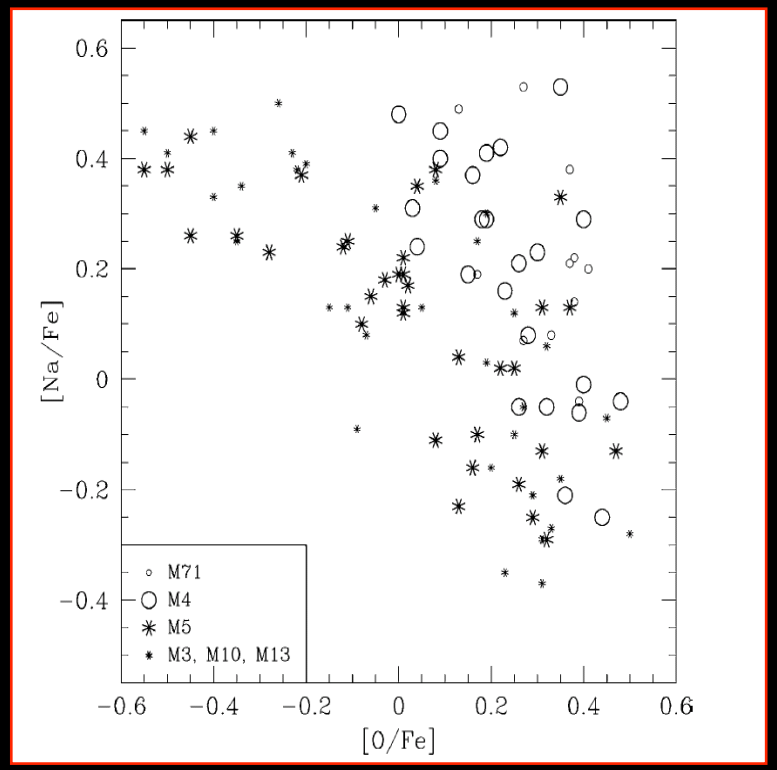
Since ’70s anti-correlations between light elements

Spectroscopy

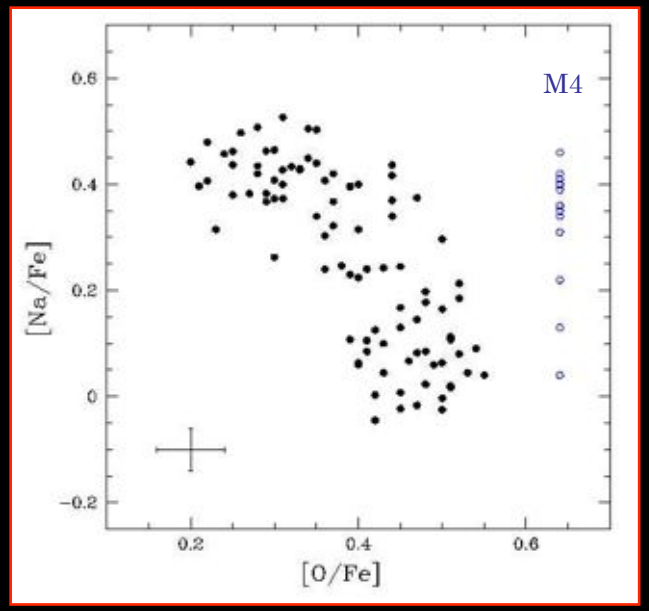
(C, N, O, Na, Mg, Al) the abundances of C, O, Mg are depleted where those of N, Na, Al are enhanced

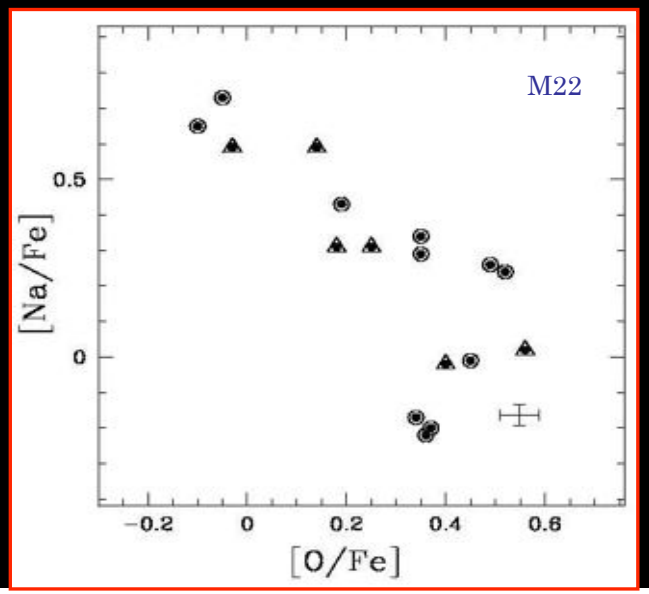
Cohen (1978); Peterson (1980); Norris (1981)

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



Marino et al. (2008, 2009)





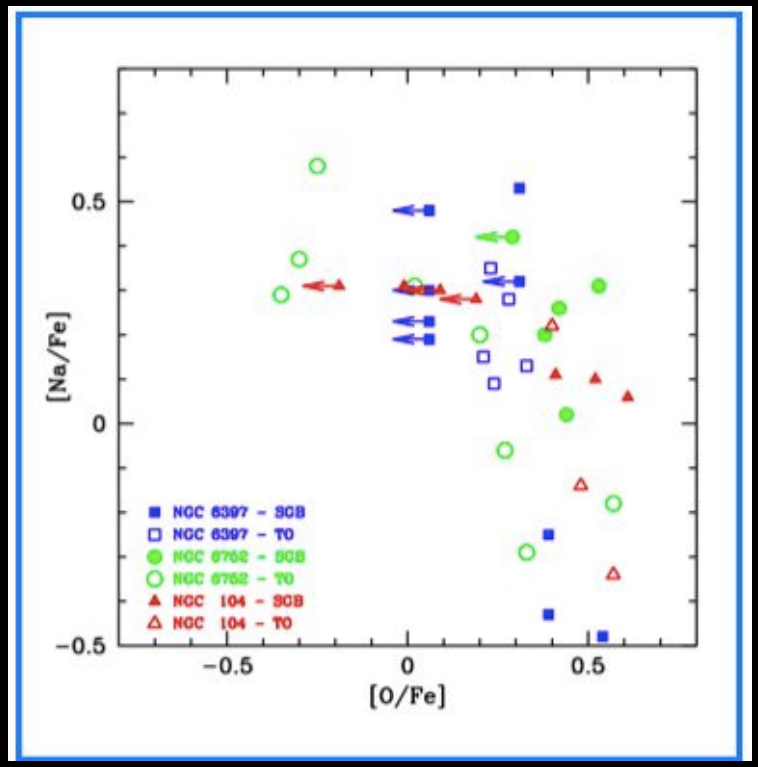
Na-O anticorrelation in GC dwarfs/subgiants

Internal mixing is ruled out:

- negligible convective envelopes

- the Al-Mg anticorrelation in TO stars in NGC 6752 requires too high core temperatures

- dominant H-burning cycle is p-p not CNO

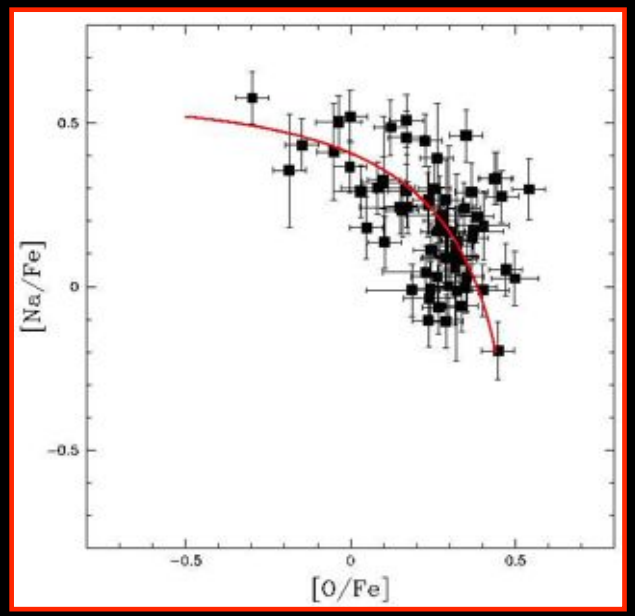


Na-O in GC dwarfs: the case of 47 Tuc

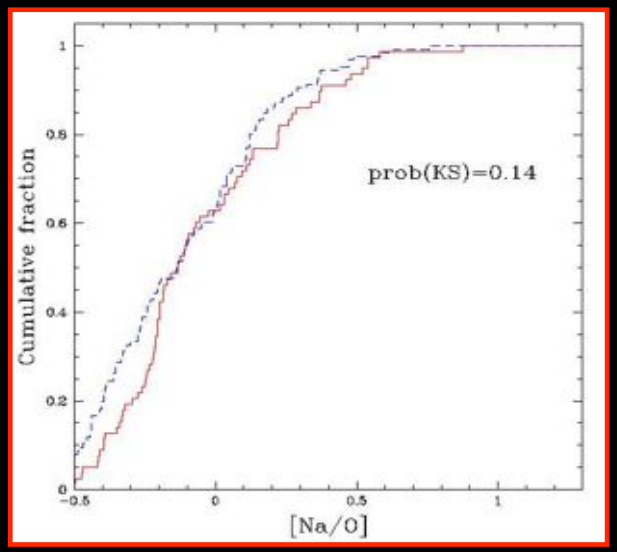
D'Orazi et al. (2010a)

~100 TO stars
FLAMES Giraffe spectra
HR15n (Li I)
HR19A (Na I @8183-8194 Å
O I @7771-7775Å)

The largest database of this kind available so far



Red solid line → dilution model(**)



✓ Na-O distributions in dwarfs and giants are identical → evolutionary effects acting during the RGB phase (D'Antona for M13) can be ruled out –at least for this cluster–

P=34 ±5 % ; I=63 ±7%; E=3 ±1%

P=27 ±5 % ; I=69 ±8%; E=4 ±2%

(Carretta et al. 2009a)

(**) $[X]=\log[(1-dil)\ x10^{[XO]} + dil\ x10^{[Xp]}]$,

where $[X_O]$ and $[X_p]$ are logarithmic abundances of

original and processed material

Prantzos & Charbonnel (2006)

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

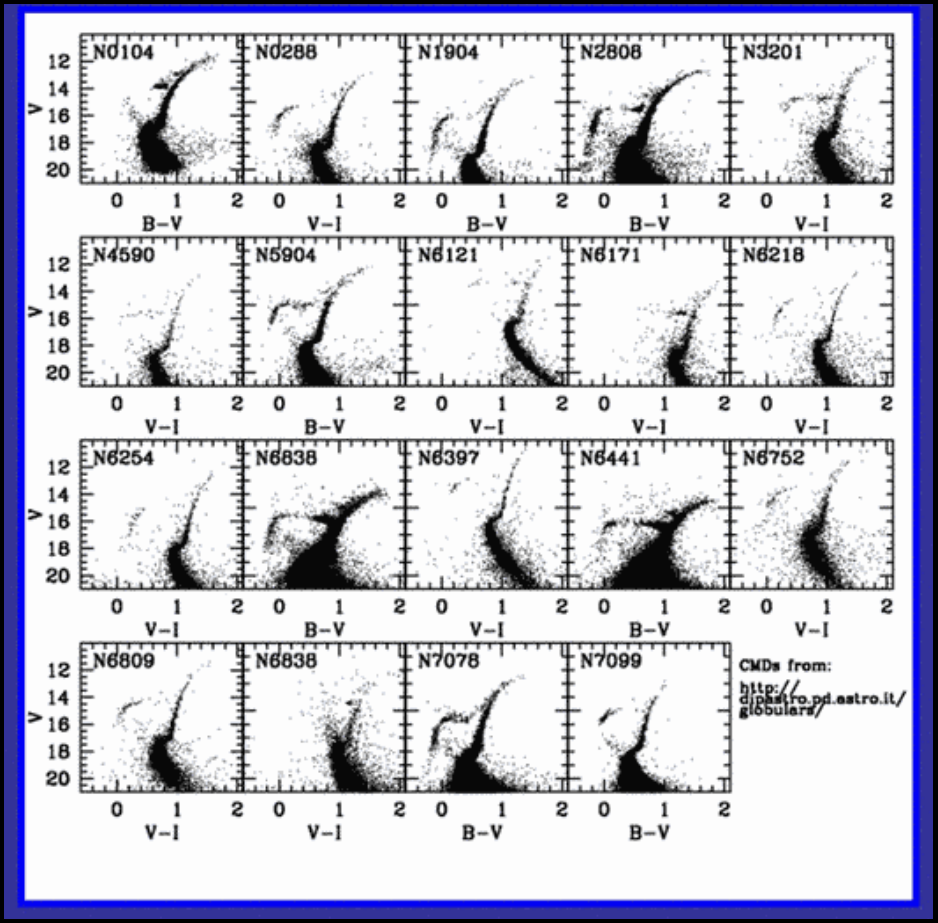
  (e.g., Ventura & D' Antona 2009)

- Winds of Fast Rotating Massive Stars

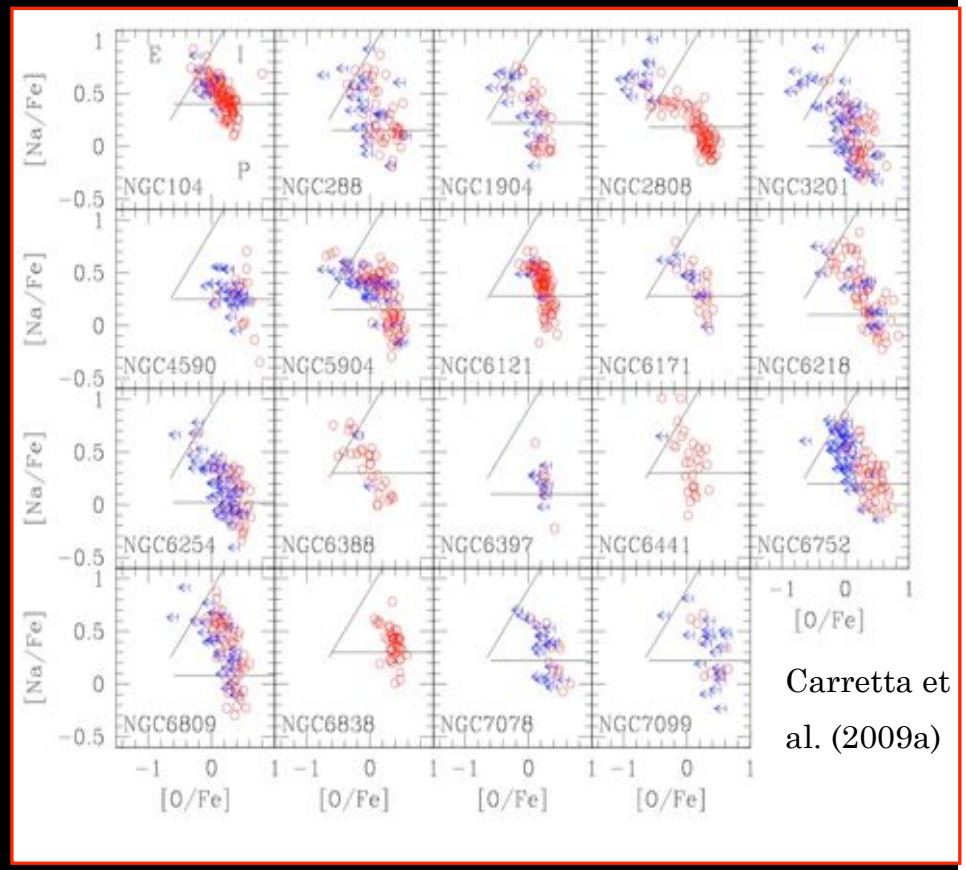
  (e.g., Decressin et al. 2007)

OUR SURVEY

✓ Na-O anticorrelation and HB in 19 GCs



FLAMES@VLT (Giraffe+UVES),>100 hrs



Carretta et al. (2009a)

Fe-peak, Na, O, Mg, Al abundances derived for ~1200 stars

P=primordial FG
I=Intermediate SG
E=Extreme SG

OUR SURVEY

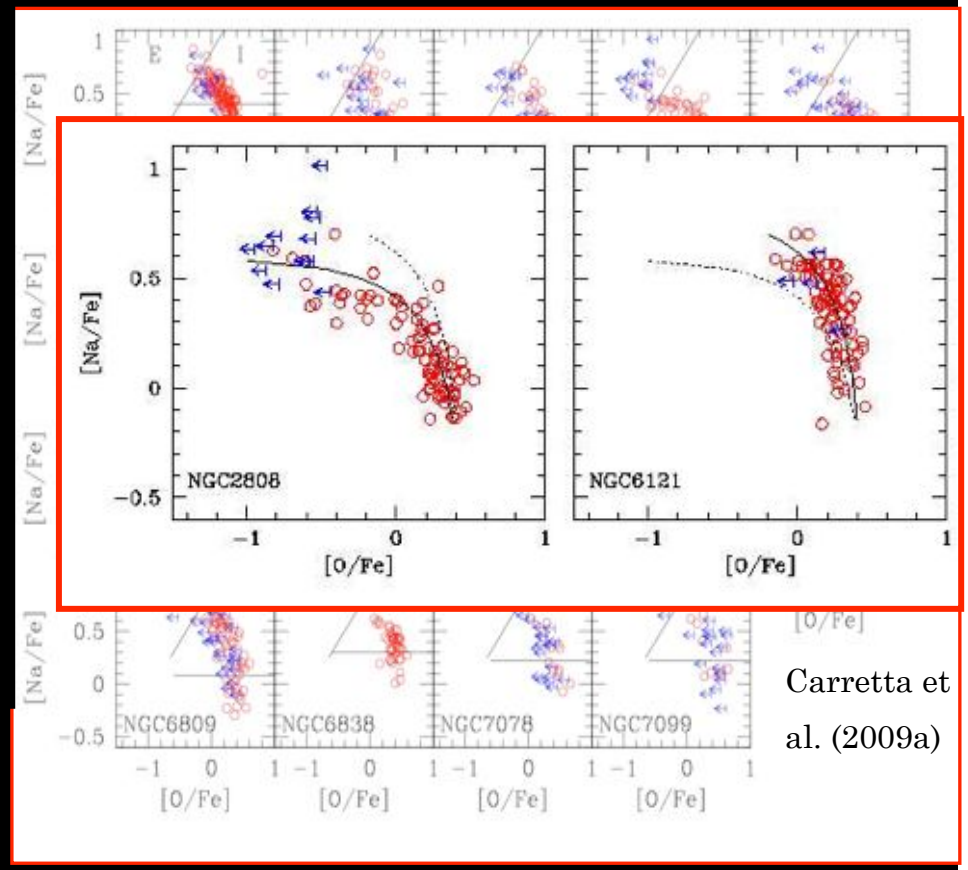
✓ Na-O anticorrelation and HB in 19 GCs

All the GCs show the Na-O anti-correlation

→ the second generation is always PRESENT

The shape of Na-O distribution changes from cluster to cluster → POLLUTER'S MASS is varying: this change is driven by both Luminosity (~mass) & Metallicity

FLAMES@VLT (Giraffe+UVES),>100 hrs



Carretta et al. (2009a)

Fe-peak, Na, O, Mg, Al abundances derived for ~1200 stars

P=primordial FG
I=Intermediate SG
E=Extreme SG

OUR SURVEY

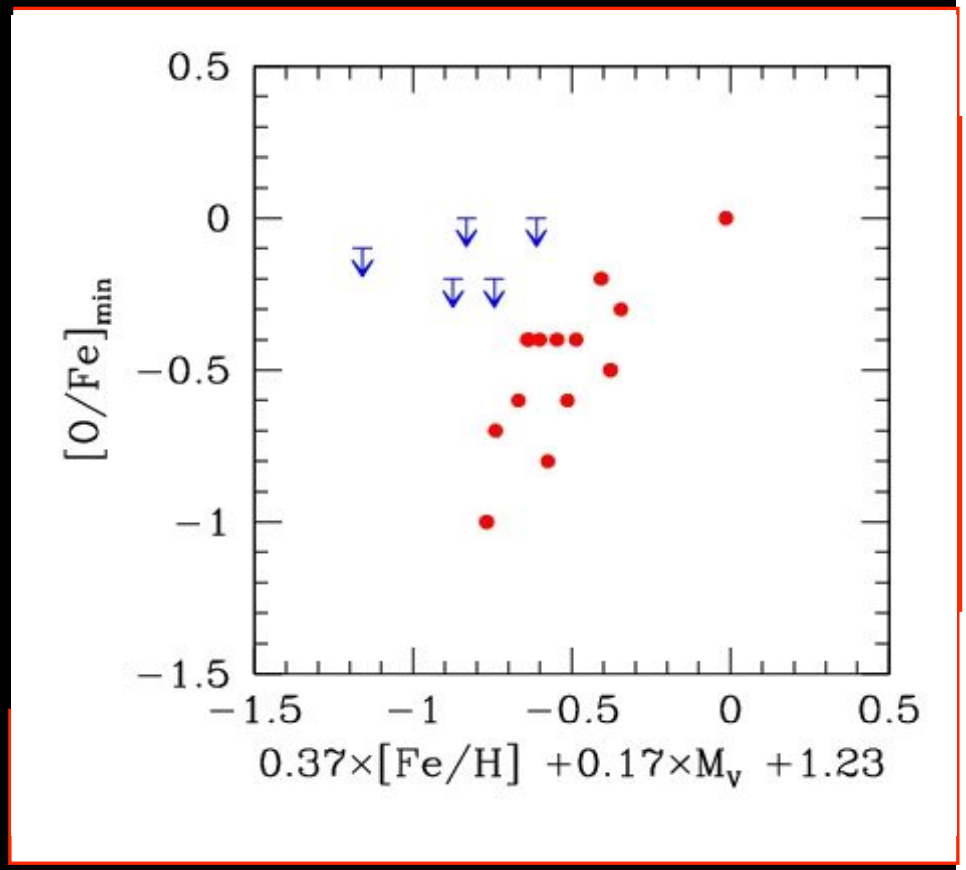
✓ Na-O anticorrelation and HB in 19 GCs

All the GCs show the Na-O anti-correlation

→ the second generation is always PRESENT

The shape of Na-O distribution changes from cluster to cluster → POLLUTER'S MASS is varying: this change is driven by both Luminosity (~mass) & Metallicity

FLAMES@VLT (Giraffe+UVES),>100 hrs

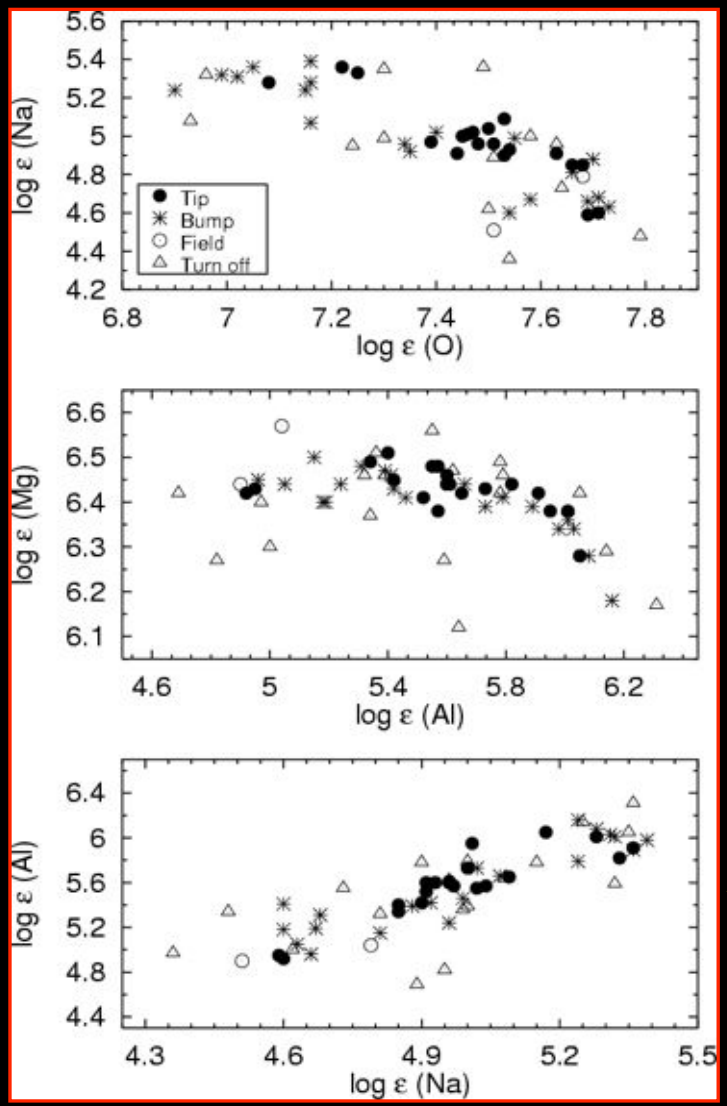


Fe-peak, Na, O, Mg, Al abundances derived for ~1200 stars

P=primordial FG
I=Intermediate SG
E=Extreme SG

The Mg-Al anticorrelation

This can also be explained through high-temperature (T~ 65 million K) proton capture nucleosynthesis, via the MgAl chain (Mg depleted, Al enhanced).



Kraft et al. 1997

Yong et al. 2003 (NGC 6752)

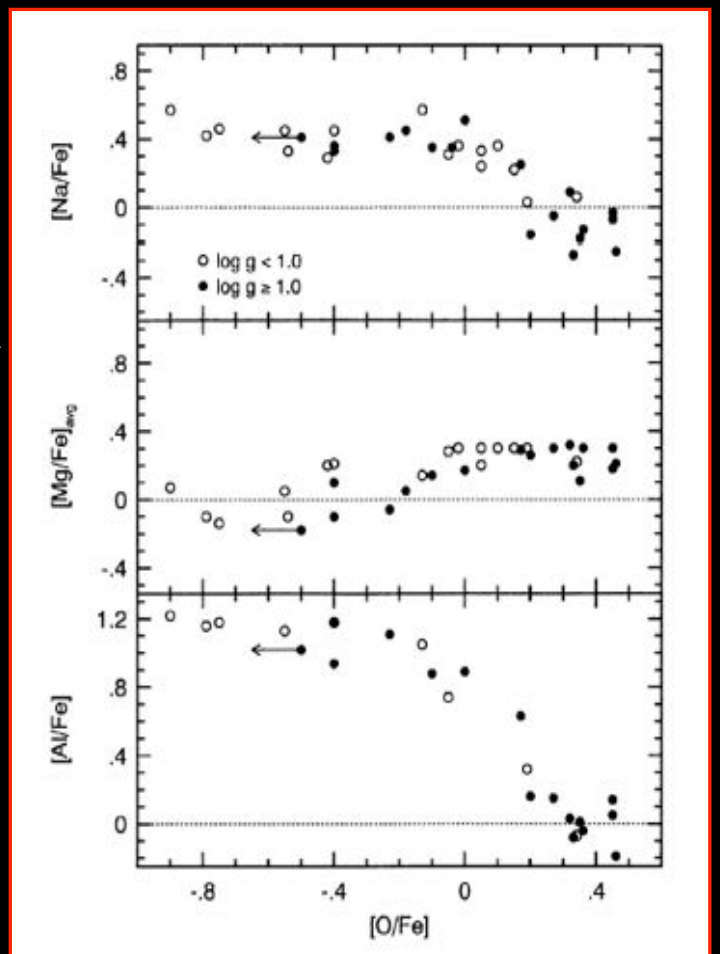
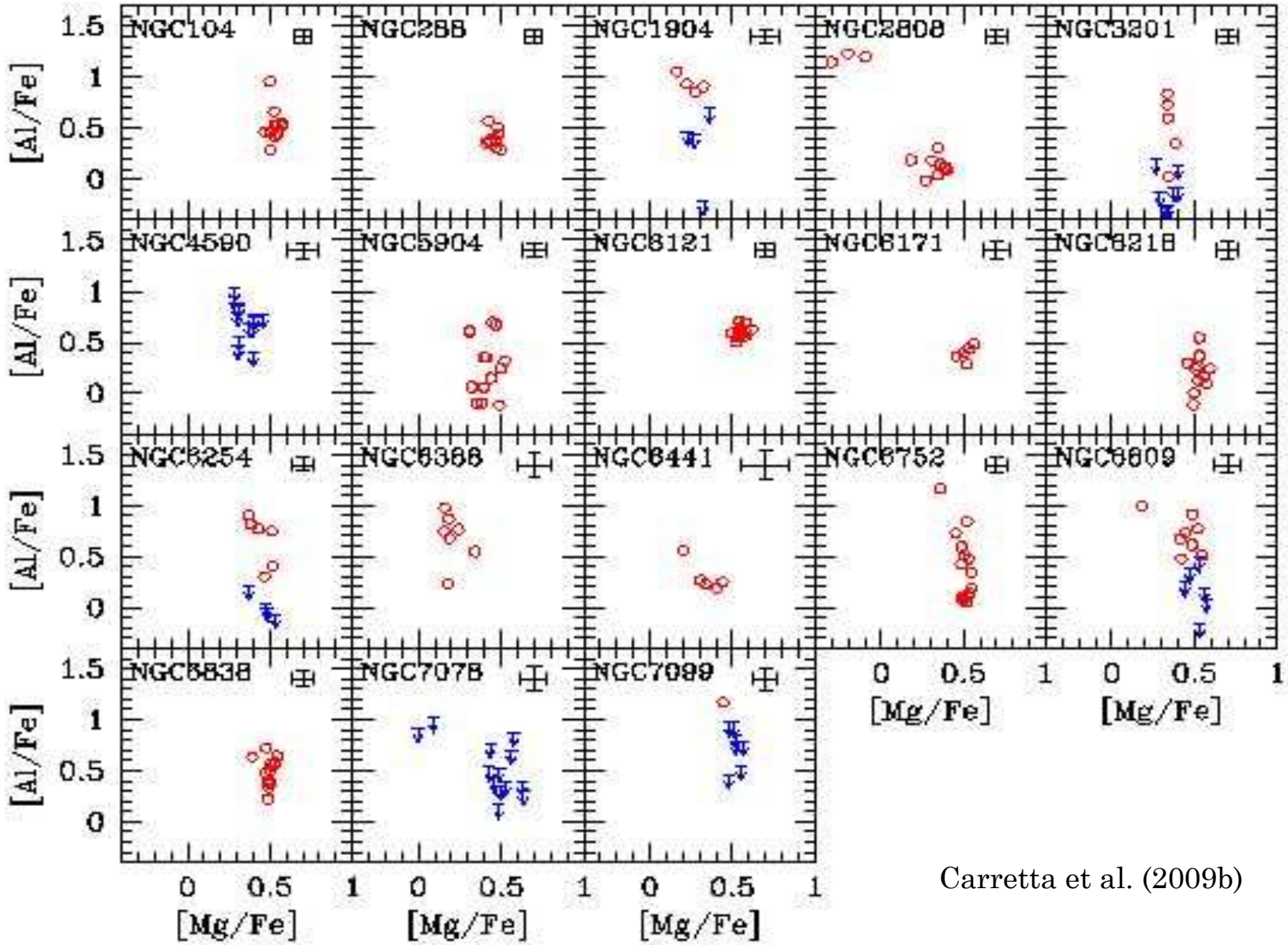
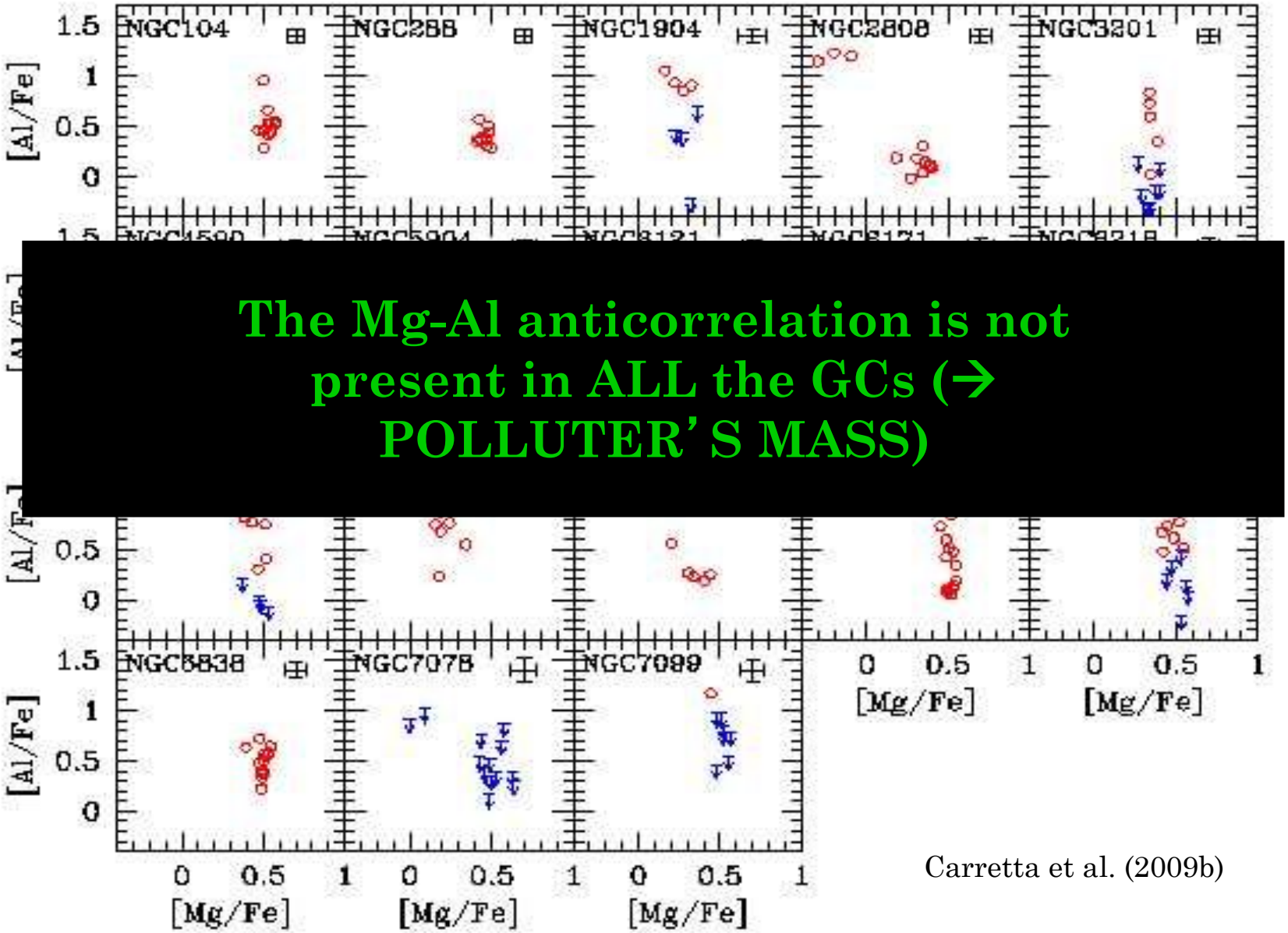


FIG. 9. Relative abundances of proton-capture elements sodium, magnesium, and aluminum as functions of relative oxygen abundances. Different symbols denote RGB tip and lower luminosity M13 giants. The horizontal dotted lines represent the solar abundances of these three elements.



Carretta et al. (2009b)

T ure



The Mg-Al anticorrelation is not present in ALL the GCs (→ POLLUTER' S MASS)

Carretta et al. (2009b)

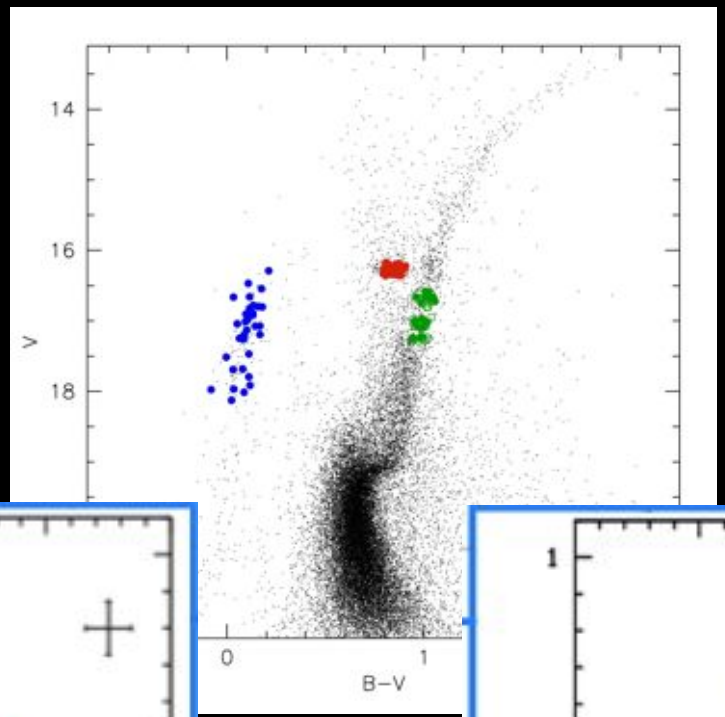
Still/partially open issues

(1) Relations with global GC parameters (mass, metallicity, HB, age..): how do GCs form?

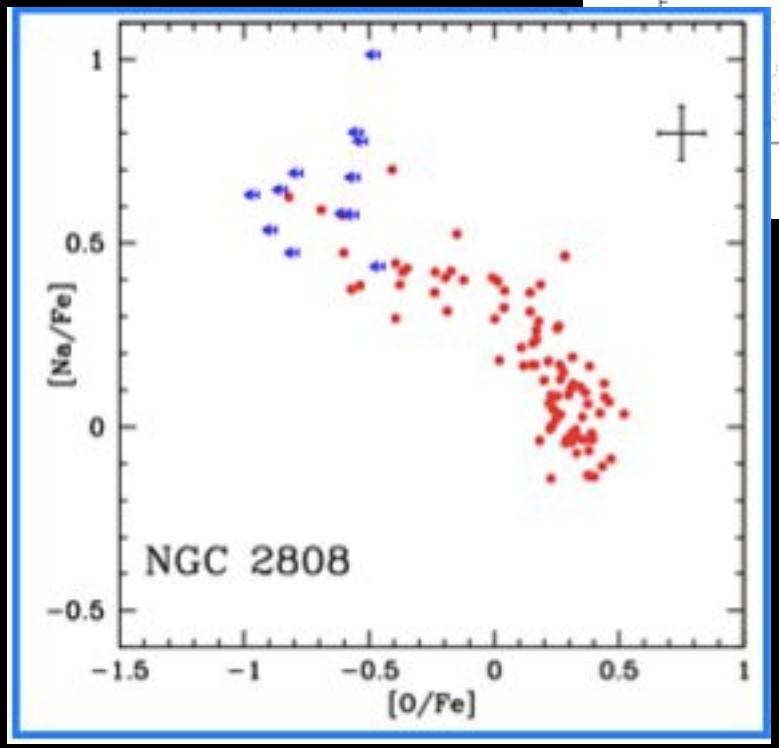
(2) The nature of polluters: which candidate polluters? Is there an universal polluter?

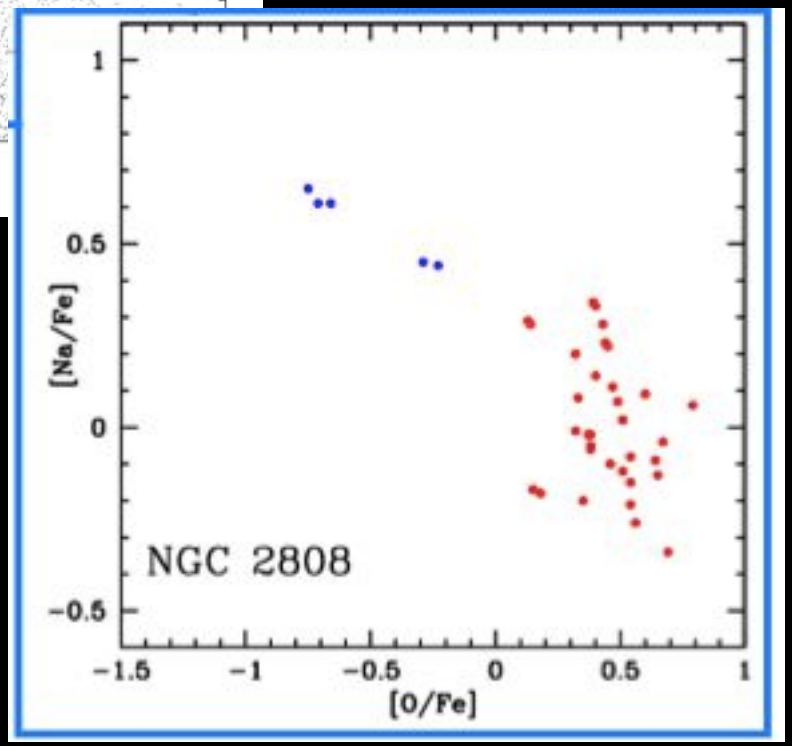
(1) Na-O anticorrelation in HB: NGC 2808

RGB
(Carretta et al. 2006)

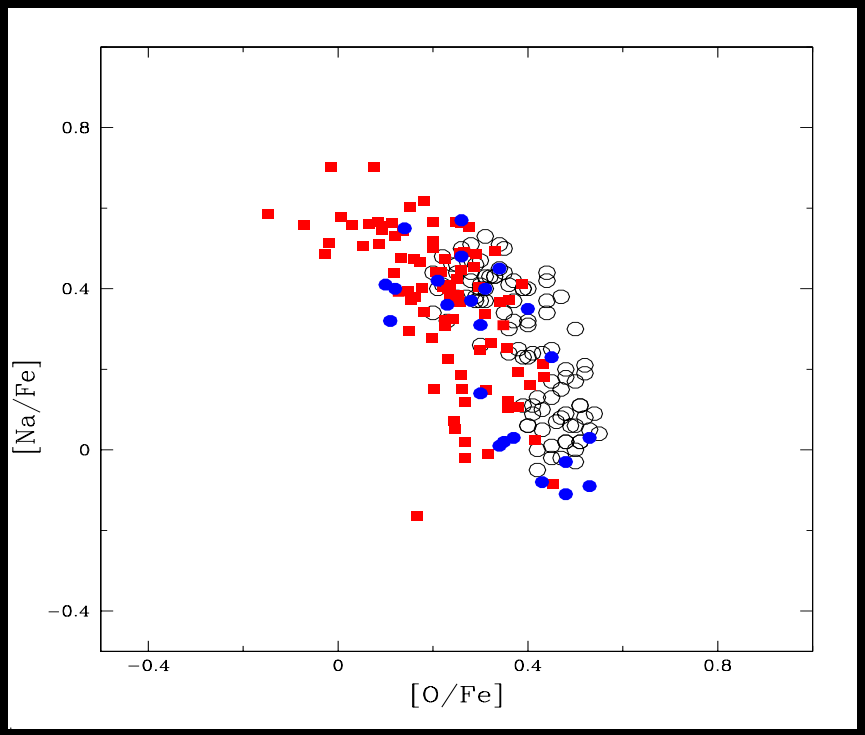


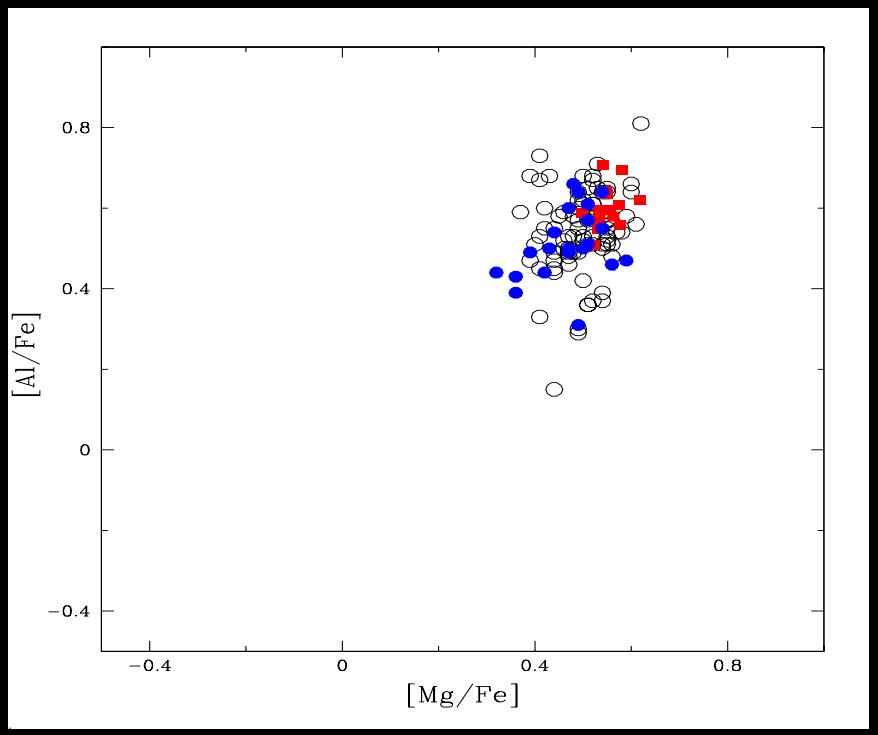
HB
(Gratton et al. 2011)





(2) FRMS vs IM-AGBs: the case of M4

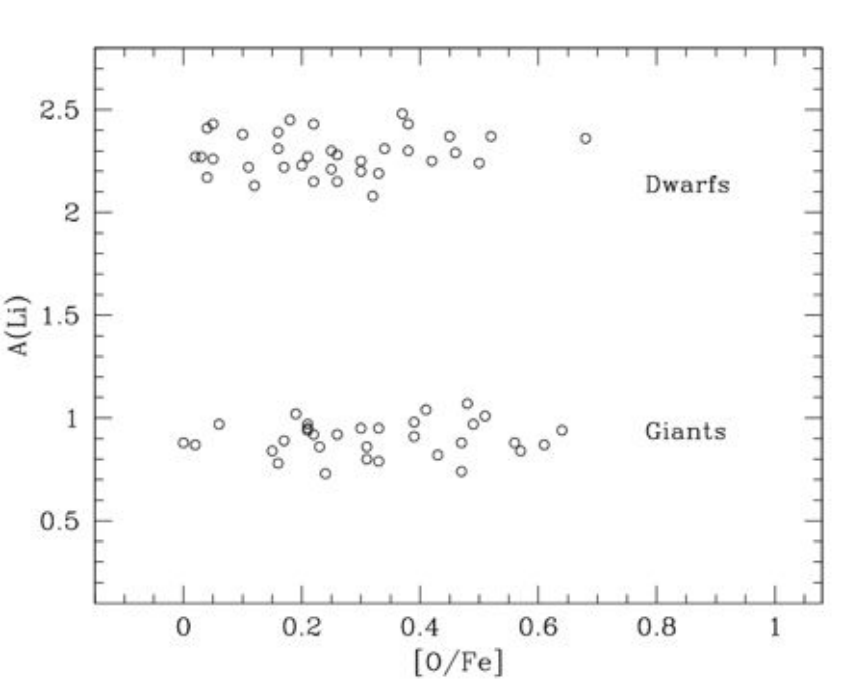




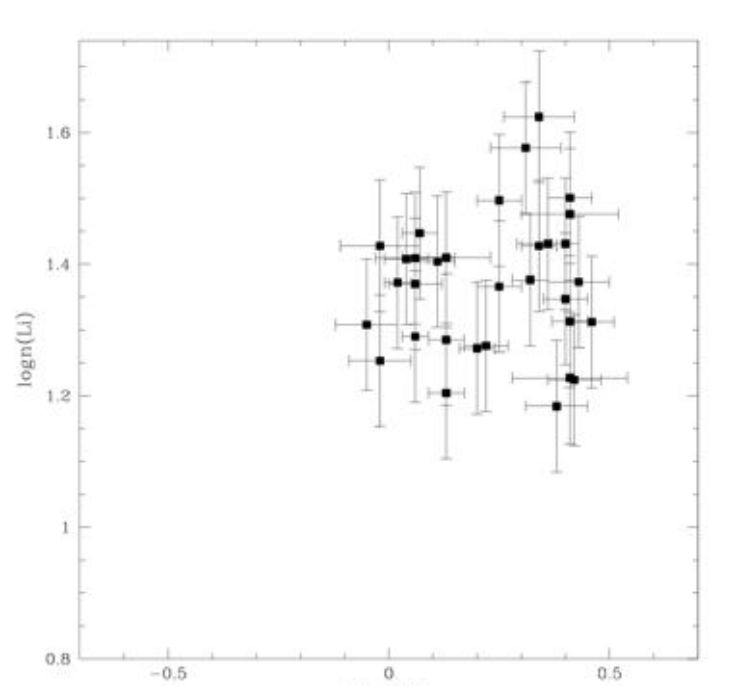
Na-O anticorrelation

NO Mg-Al anti-correlation

Run of Li with Oxygen and Sodium



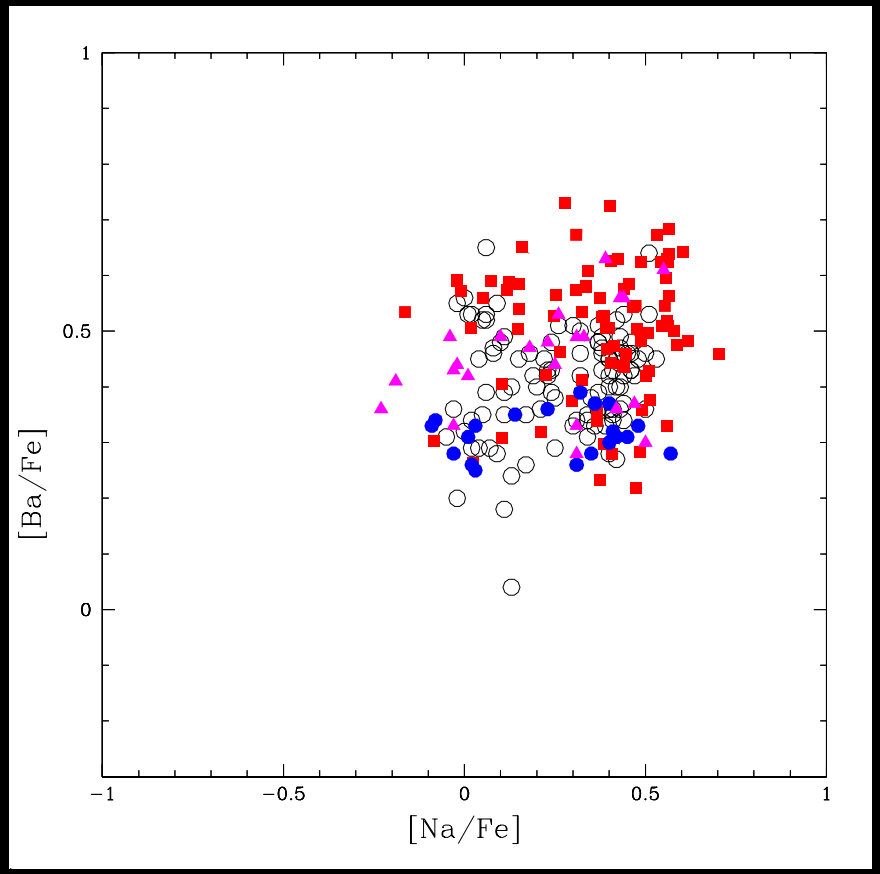
Mucciarelli + 2011



D'Orazi & Marino + 2010

WE MUST HAVE A LITHIUM PRODUCTION BETWEEN FIRST AND SECOND GENERATION STARS

FRMS can ONLY destroy Lithium, while IM-AGBs can also produce it



Ba and s-process elements (from Rb→ Sr → Pb):
CONSTANT

1st AGB MODEL: 3 Msun (Z=0.002; α-enhanced)

by M. Lugaro & S. Campbell

[O/Fe] ~ 0.10 dex

[Na/Fe] ~ 0.5 dex

[Mg/Fe]~0.3 dex

[Al/Fe] ~ 0.15 dex

[Sr/Fe] ~ 0.3 dex

[Y/Fe] ~ 0.3 dex

[Ba/Fe] ~ 0.05 dex

2st AGB MODEL: 4 Msun (Z=0.002; α-enhanced)

[O/Fe] ~ 0.07 dex

[Na/Fe] ~ 0.6 dex

[Mg/Fe]~ 0.3 dex

[Al/Fe] ~ 0.14 dex

[Sr/Fe] ~ 0.70 dex

[Y/Fe] ~ 0.65 dex

[Ba/Fe] ~ 0.20 dex

3st AGB MODEL → 6 Msun :

(Z=0.002 alpha-enhanced)

(a) Mass loss law by Vassiliadis & Wood (1993)

(b) Mass loss law by Blocker (1995)

Core team: future charges

VD (Lithium and Fluorine vs O and Na)

Angela Bragaglia (MS stars NGC2808 Xshooter; small clusters)

Eugenio Carretta (Al in ~ 400 RGB stars; complete Na-O antic.)

Raffaele Gratton (Na-O anticorrelation in HB stars)

Sara Lucatello (young, massive clusters; binaries in P,I,E stars)

Stay tuned....