Globular Clusters:

a chemical roadmap between anomalies

and homogeneity

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

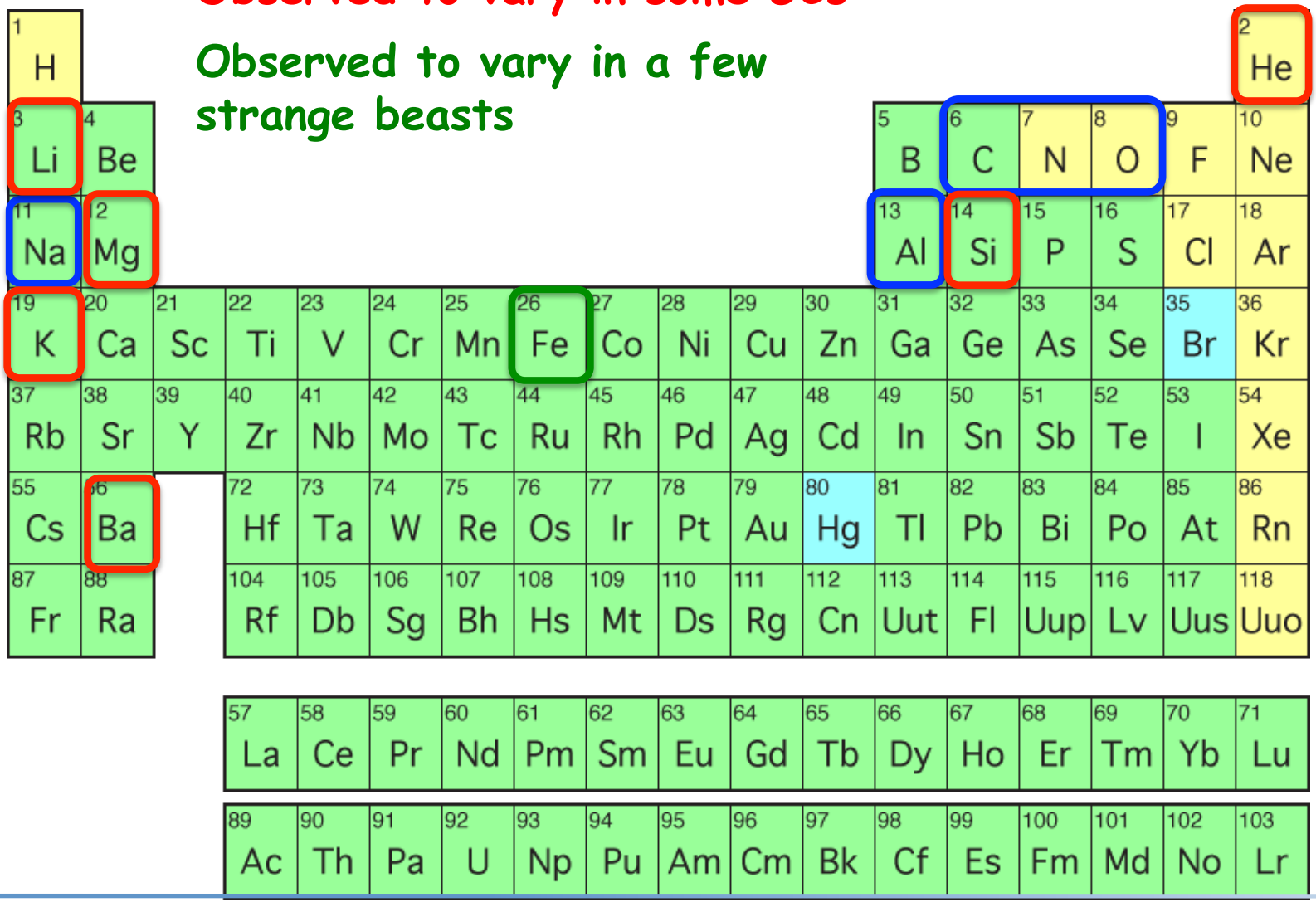
- Stellar evolution
- Chemical enrichment history of the parent galaxy
- Unresolved Stellar Populations

.....

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)

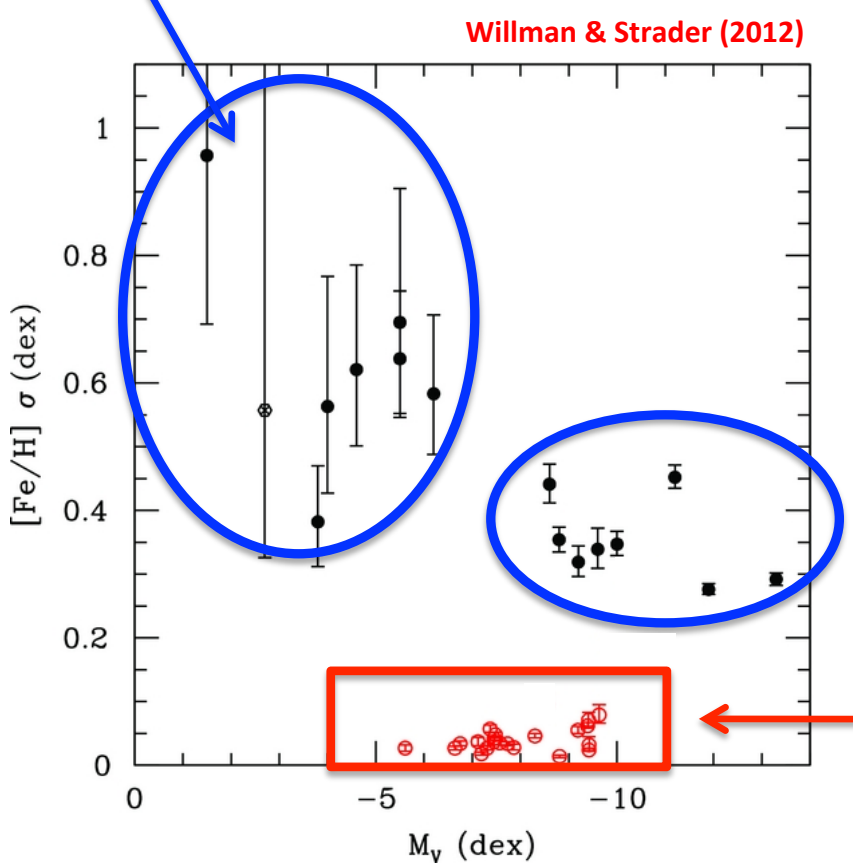
Fe produced by SN II + SN Ia

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)

Ultra-faint dwarfs



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

dSphs

GCs (spread < 0.05 dex)

Strange beasts … Fe spreads !!!

- Omega Centauri
- Terzan 5
- M54
- M22
- NGC 1851

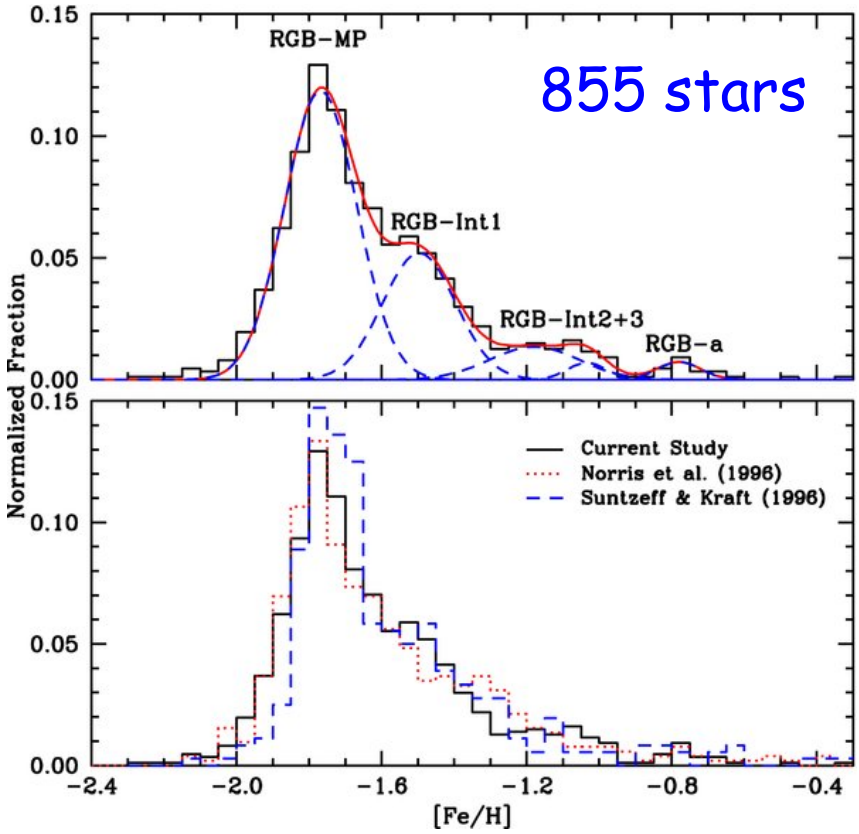
Metallicity distribution

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

It is NOT a genuine GC

(remnant of a dwarf?)

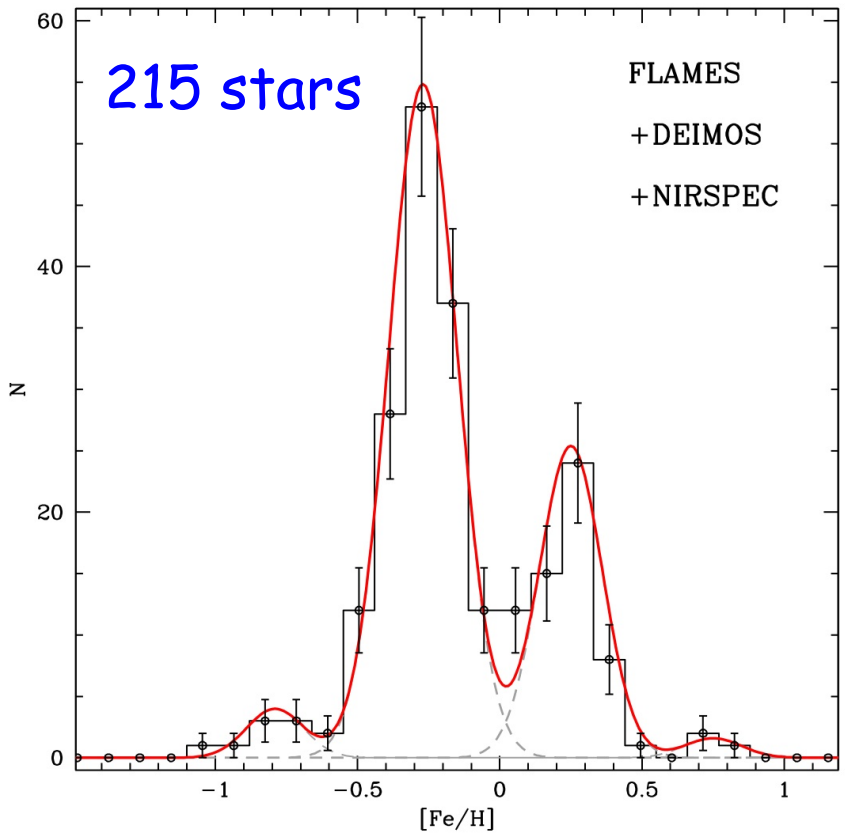
Johnson & Pilachowski (2009)



Strange beasts … Fe spreads !!!

- Omega Centauri
- Terzan 5 (see talk by D. Massari)
- M54
- M22
- NGC 1851

Massari et al. (in prep.)



Metallicity distribution

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

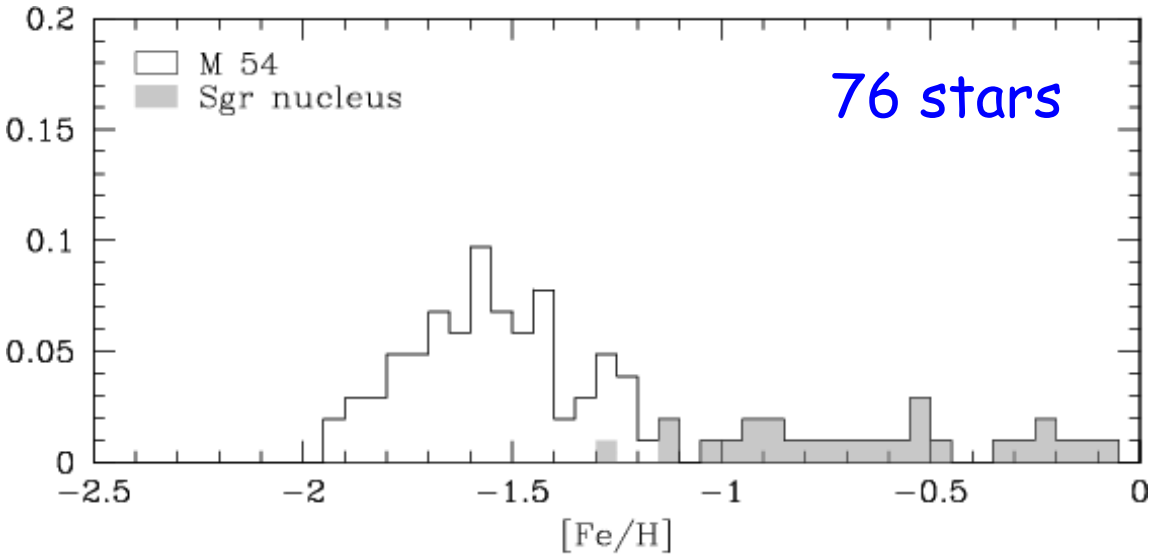
It is NOT a genuine GC

Strange beasts … Fe spreads !!!

A massive GC immersed
in the nucleus of the Sgr dSph

- Omega Centauri
- Terzan 5
- M54
- M22
- NGC 1851

Carretta et al. (2010)



Metallicity distribution

- Broad
- Uni-modal

Strange beasts … Fe spreads !!!

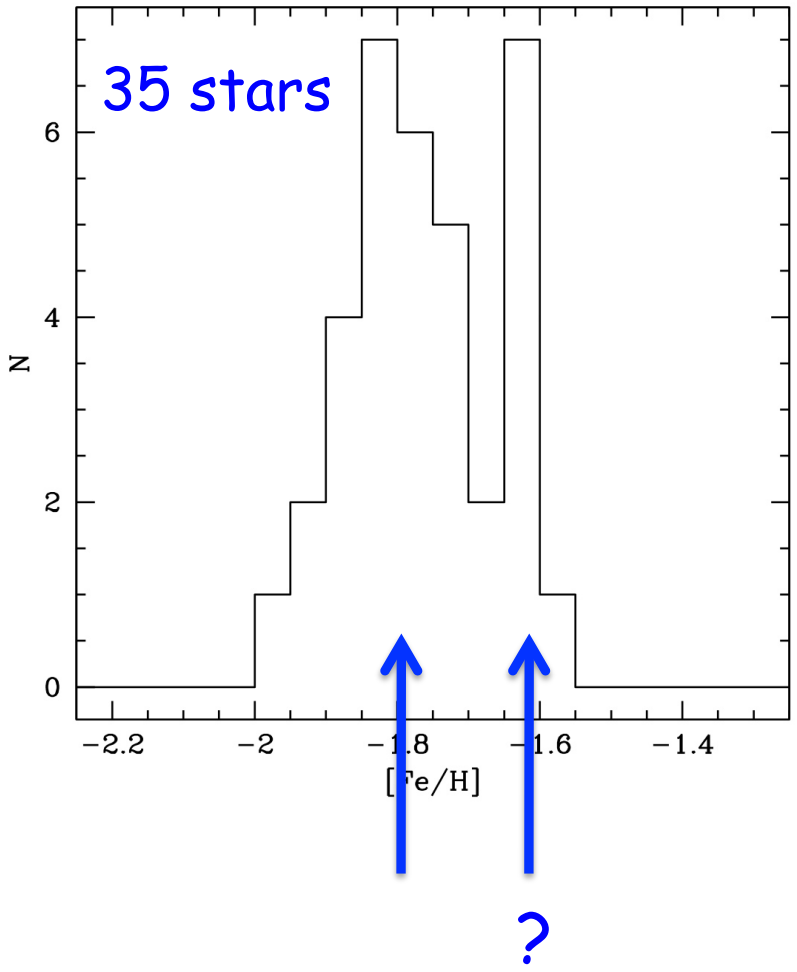
First evidence of Fe spread
by Pilachowski et al. (1982)

- Omega Centauri
- Terzan 5
- M54
- M22
- NGC 1851

Metallicity distribution

- Broad
- Uni-modal (?)

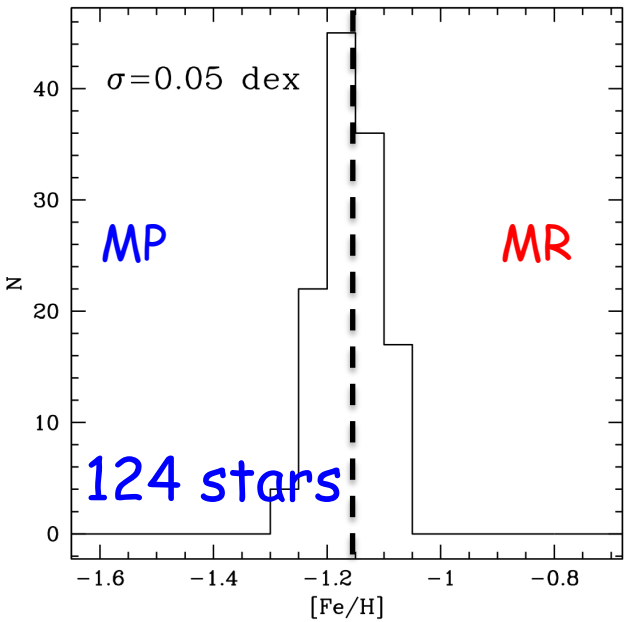
Marino et al. (2011)



Strange beasts … Fe spreads !!!

- Omega Centauri
- Terzan 5
- M54
- M22
- NGC 1851

Carretta et al. (2011)



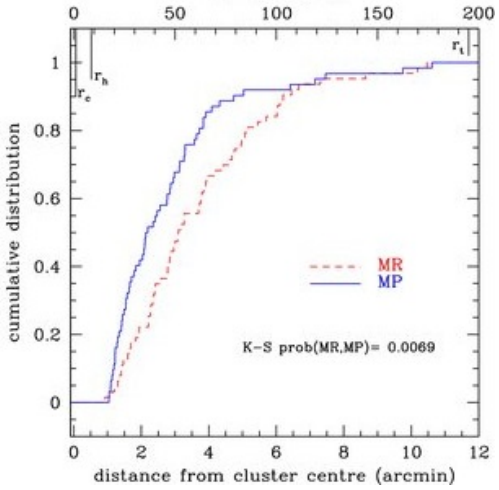
Metallicity distribution

- Broad (?)
- uni-modal

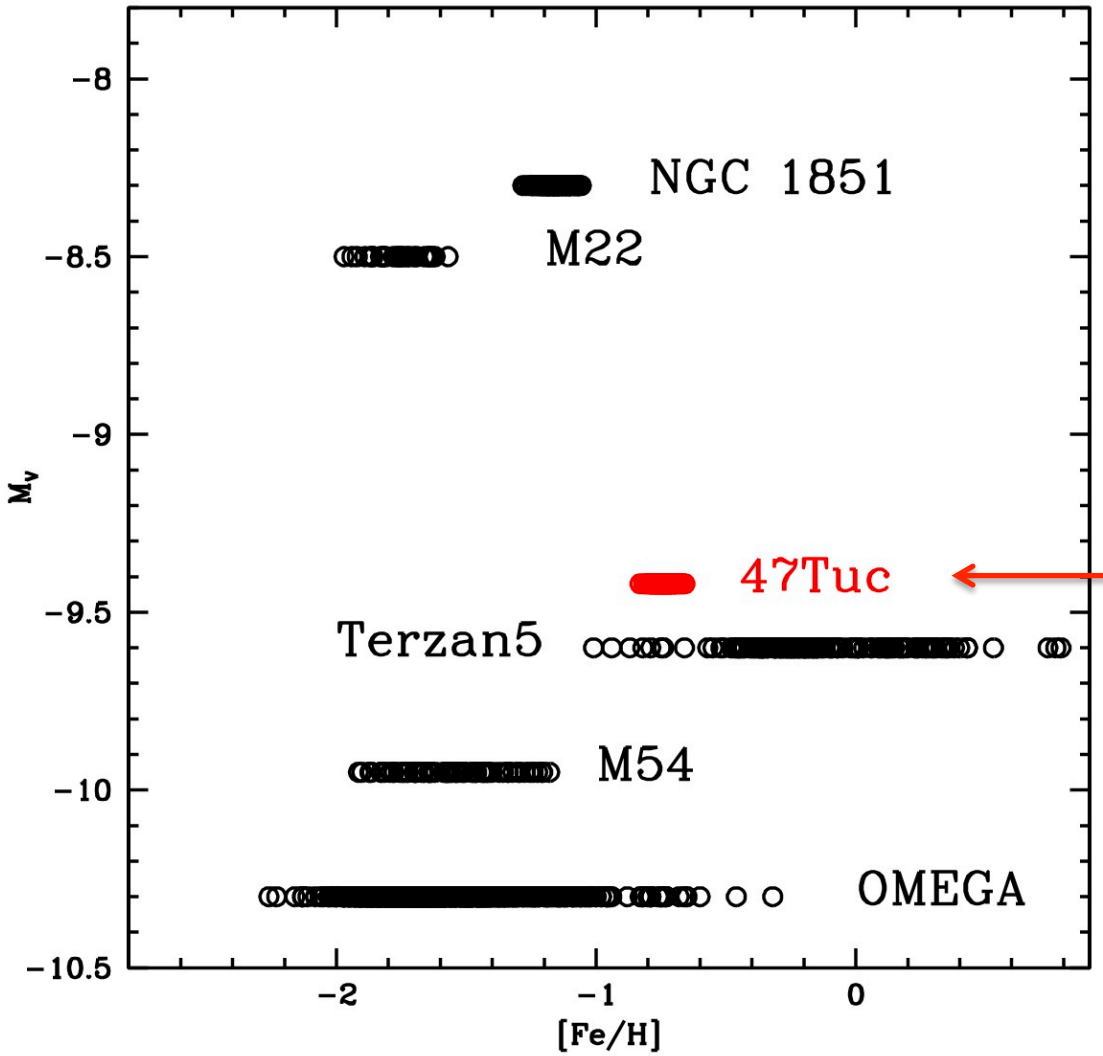
… but other authors do not find Fe spreads

(Yong & Grundahl 2008, Villanova et al. 2010)

Different radial distribution

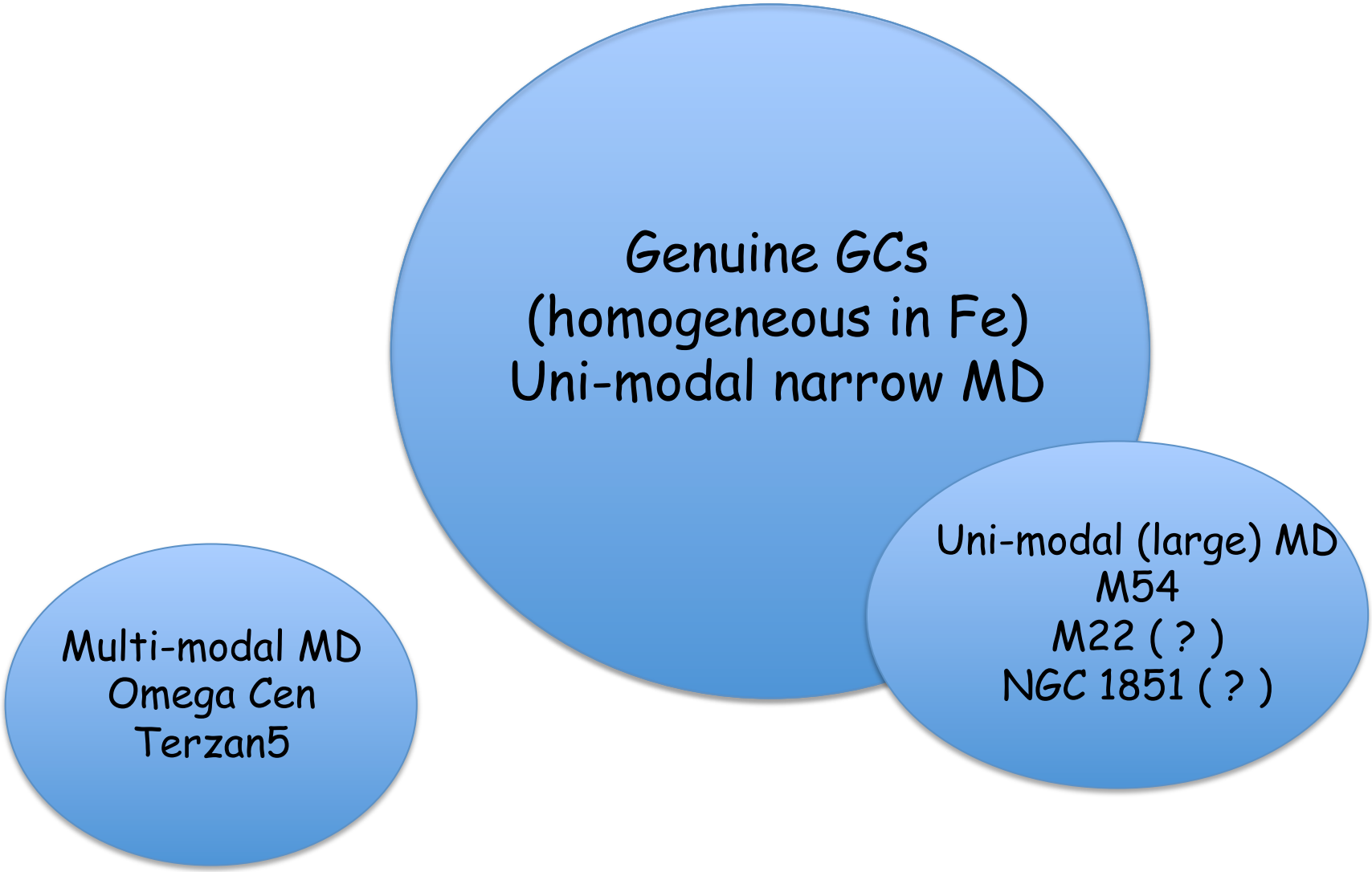


Merging ?



A NORMAL GC

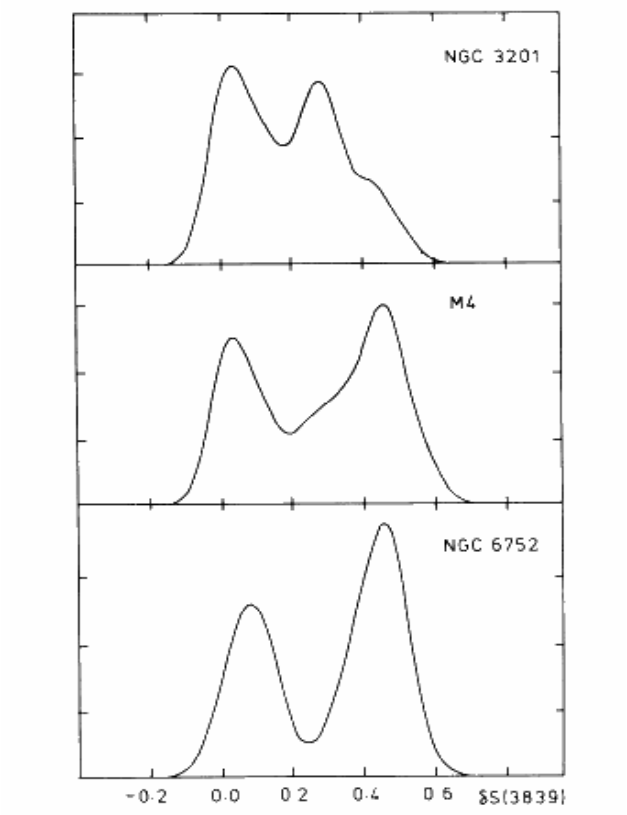
GCs zoology …


Genuine GCs
(homogeneous in Fe)
Uni-modal narrow MD
Uni-modal (large) MD
M54
M22 (?)
NGC 1851 (?)
Multi-modal MD
Omega Cen
Terzan5

Light elements (C, N, O, Na, Al)

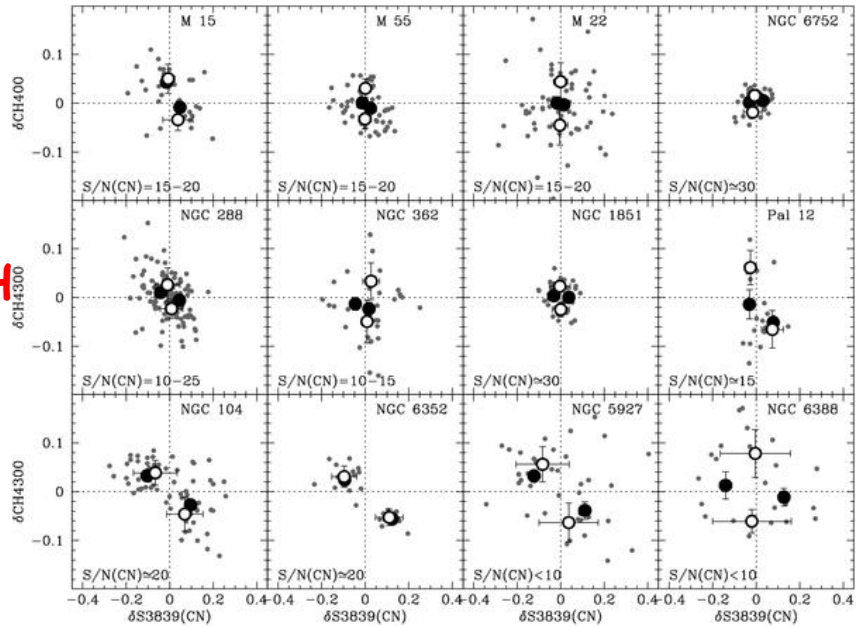
Something of strange since 40 years ago
(Osborn 1971, 2 CN-strong stars in M5 & M10)

Smith & Norris (1982)



CN

Pancino et al. (2009)



CH

CN

CN-strong stars observed only in GCs
CNO-cycle !!!

Light elements (C, N, O, Na, Al)

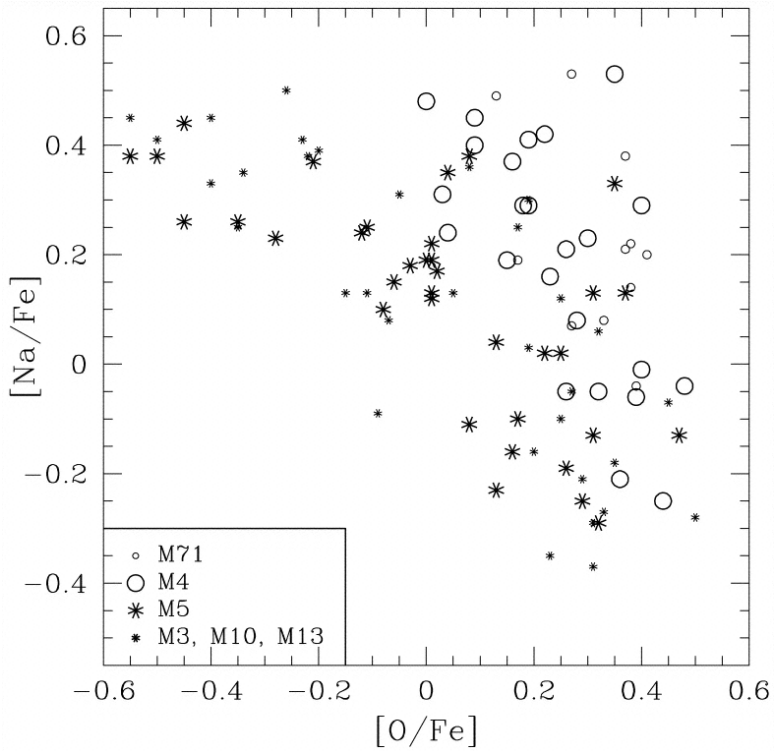
High-res spectroscopy

CN-Na/Al correlation (Cottrell & Da Costa 1981)

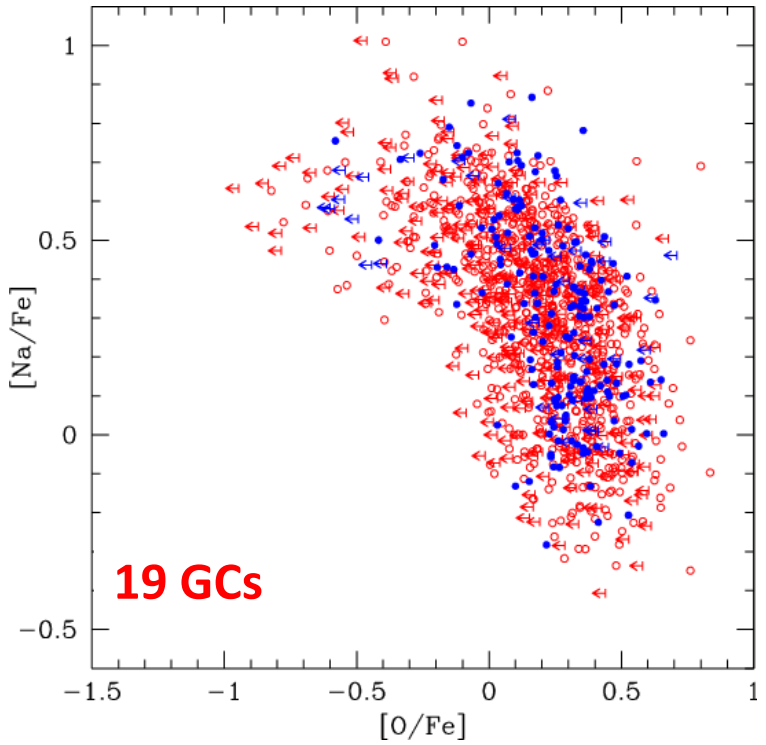
CN-O correlation (Sneden et al. 1992)

Na-O anticorrelation (Kraft et al. 1992,1994)

Ivans et al. (2001)



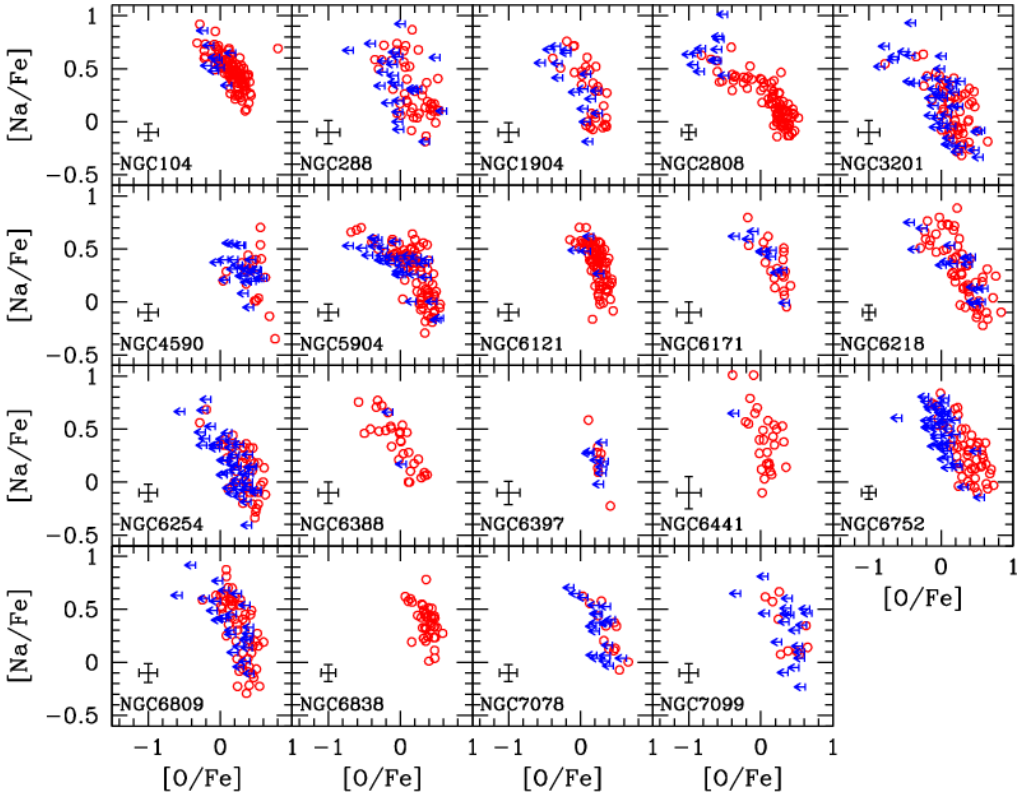
Carretta et al. (2009)



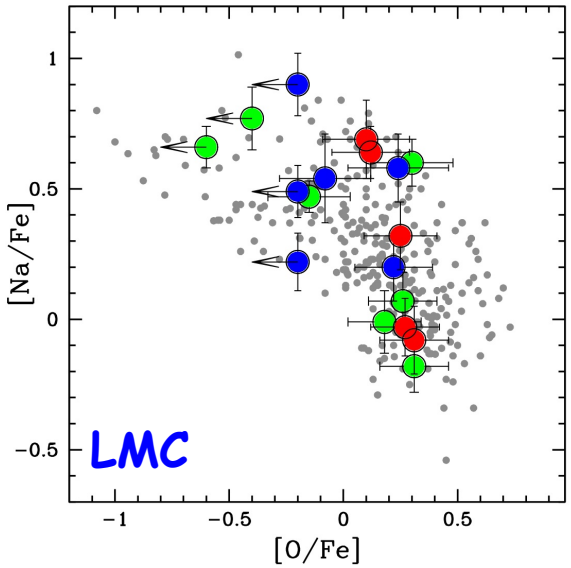
Light elements (C, N, O, Na, Al)

The shape/extension of NaO depends on the cluster

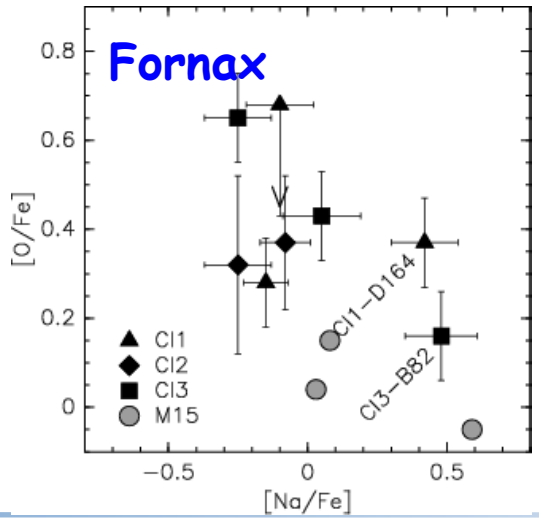
Carretta et al. (2009)



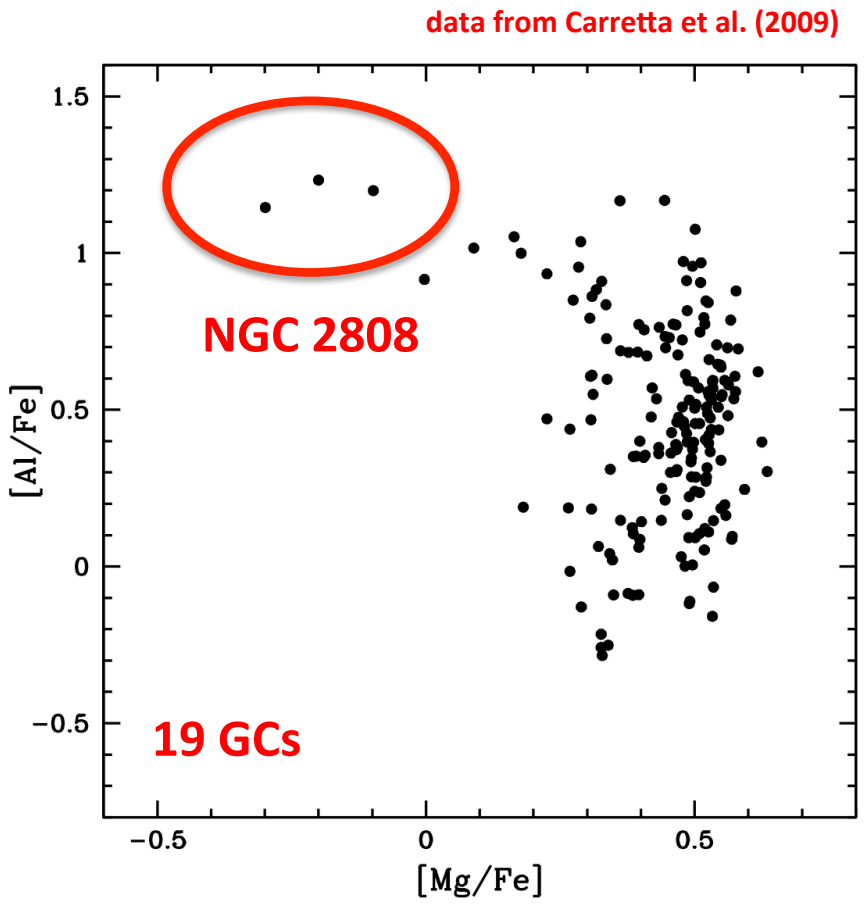
Mucciarelli et al. (2009)



Letarte et al. (2006)



Light elements (C, N, O, Na, Al)



Mg-Al anticorrelation:

It is not a true anticorrelation

Al spread + (some) Mg-poor stars

Subsolar Mg-stars

3 in NGC 2808 (Carretta et al. 2006)

1 in NGC 1786 (LMC, Mucciarelli et al. 2009)

Several in NGC 2419

(Cohen et al. 2010, Mucciarelli et al. 2012)

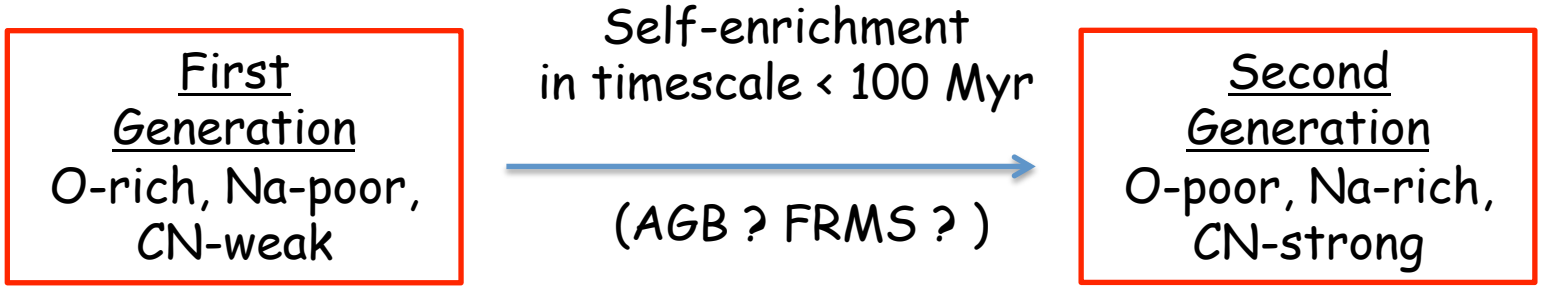
A general framework for GCs chemical anomalies

- CN-CH anticorrelation
- CN bimodality
- NaO anticorrelation
- MgAl anticorrelation

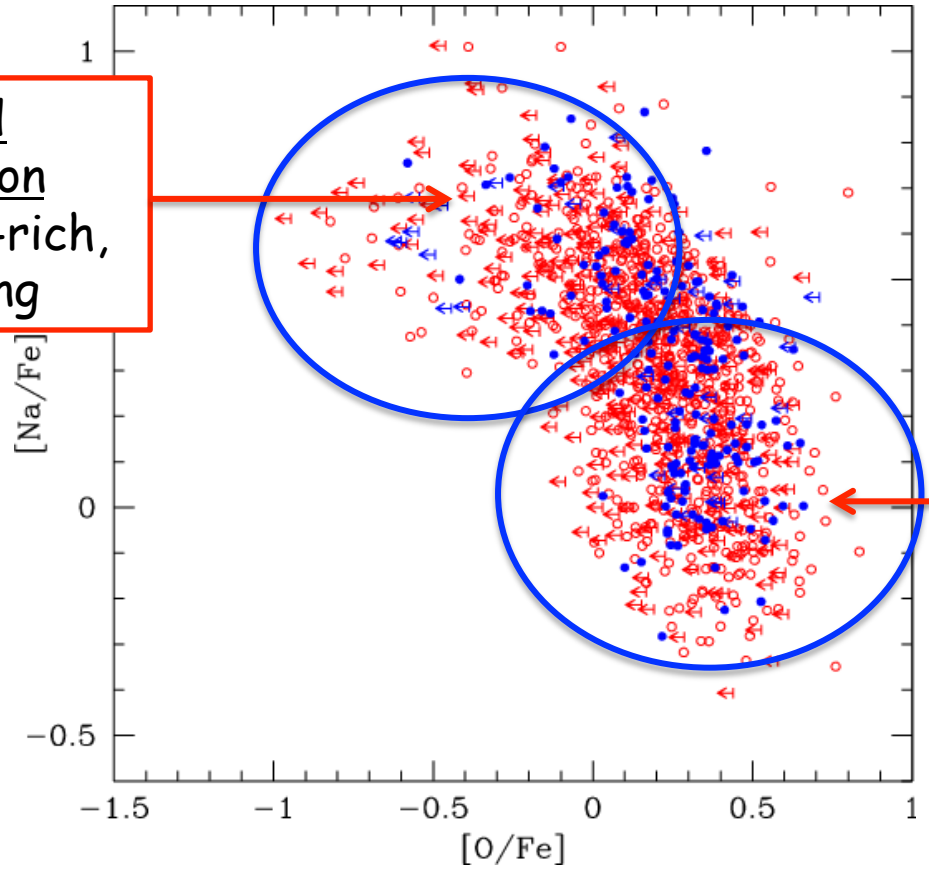
Signatures of hot **H-burning** CNO, NeNa and MgAl chains

Several models (and open issues)

D'Ercole et al. (2008), Decressin et al. (2010), Bekki (2011), Conroy & Spergel (2011), Valcarce & Catelan (2011) …



Brutal but efficient classification



Second Generation
O-poor, Na-rich, CN-strong

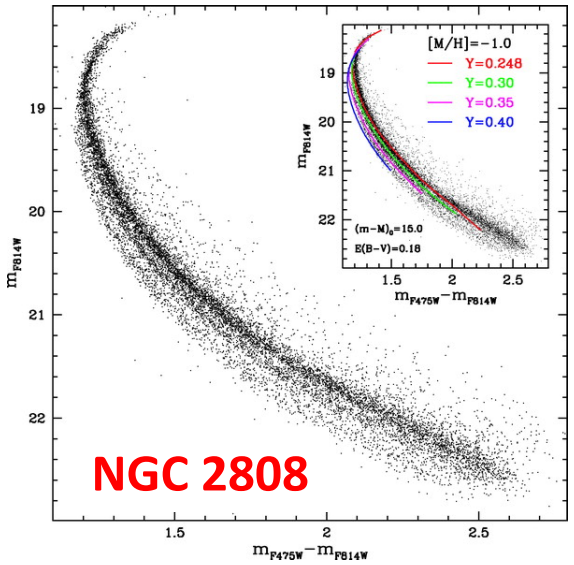
First Generation
O-rich, Na-poor, CN-weak

Helium

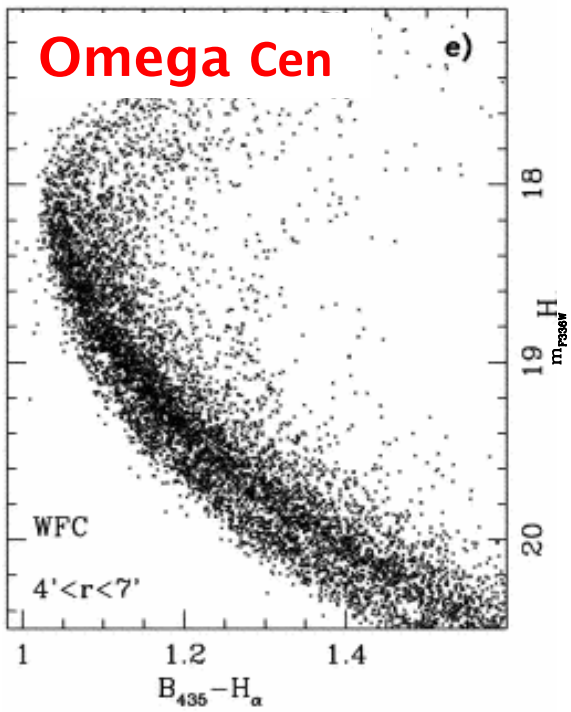
He is the main product of the H-burning

Photometric evidences (MS splitting + Blue HB)
of (mild or extreme) He enhancement (up to Y~0.4)

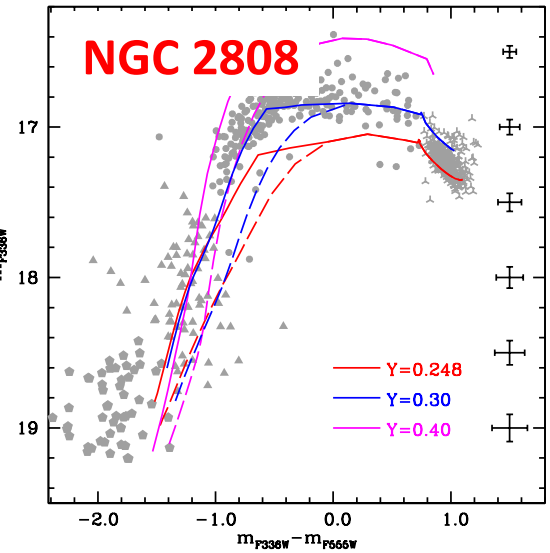
Piotto et al. (2007)



Bedin et al. (2004)



Dalessandro et al. (2011)

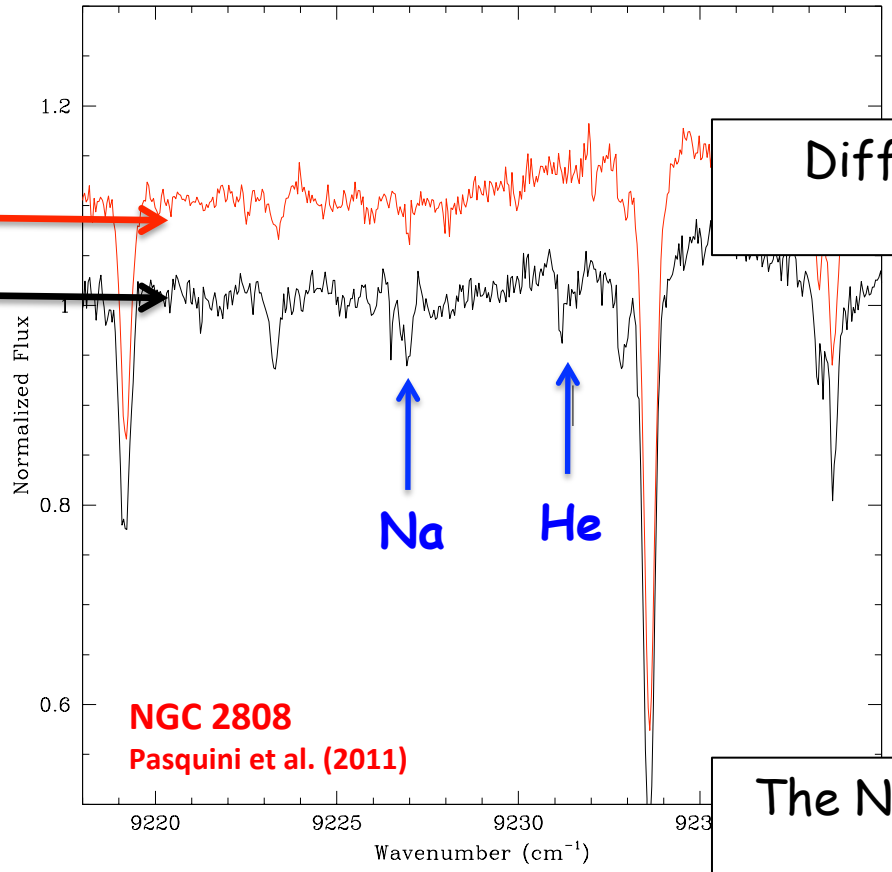


Helium in RGB

He @10820 Å

Na-poor giant

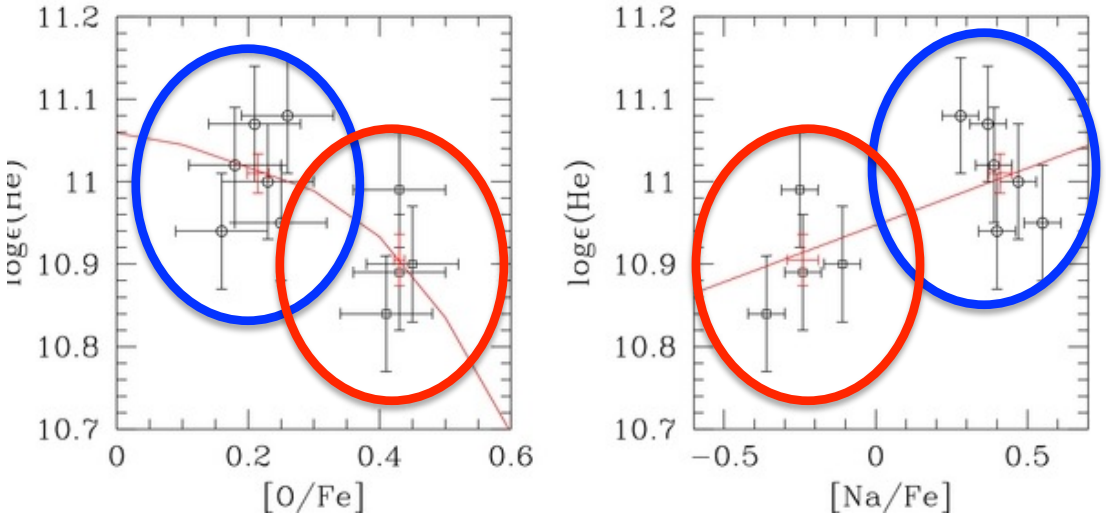
Na-rich giant



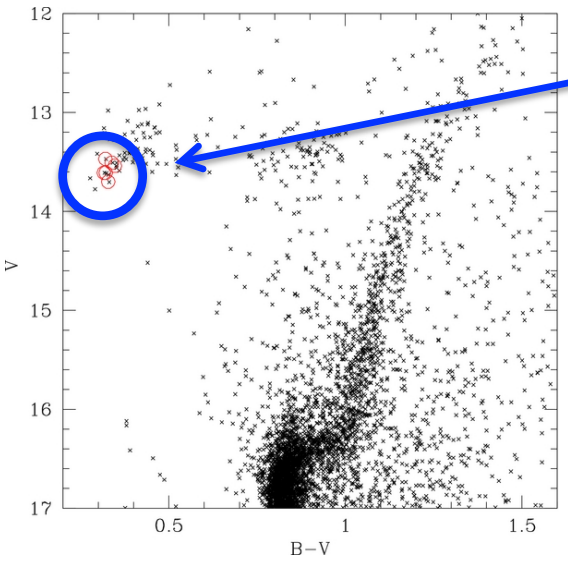
Differential analysis
$\Delta Y \geq 0.17$

The Na-rich star is more He-rich than the Na-poor star.

Helium in HB



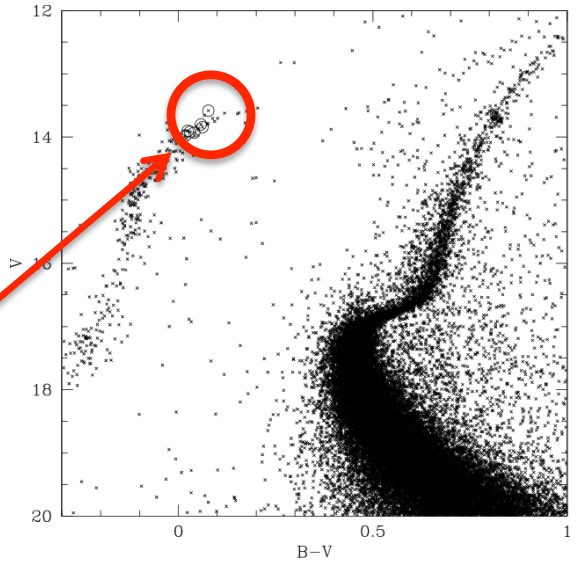
M4 Villanova et al.(2011)



Y=0.29
O-poor/Na-rich

Y=0.25
O-rich/Na-poor

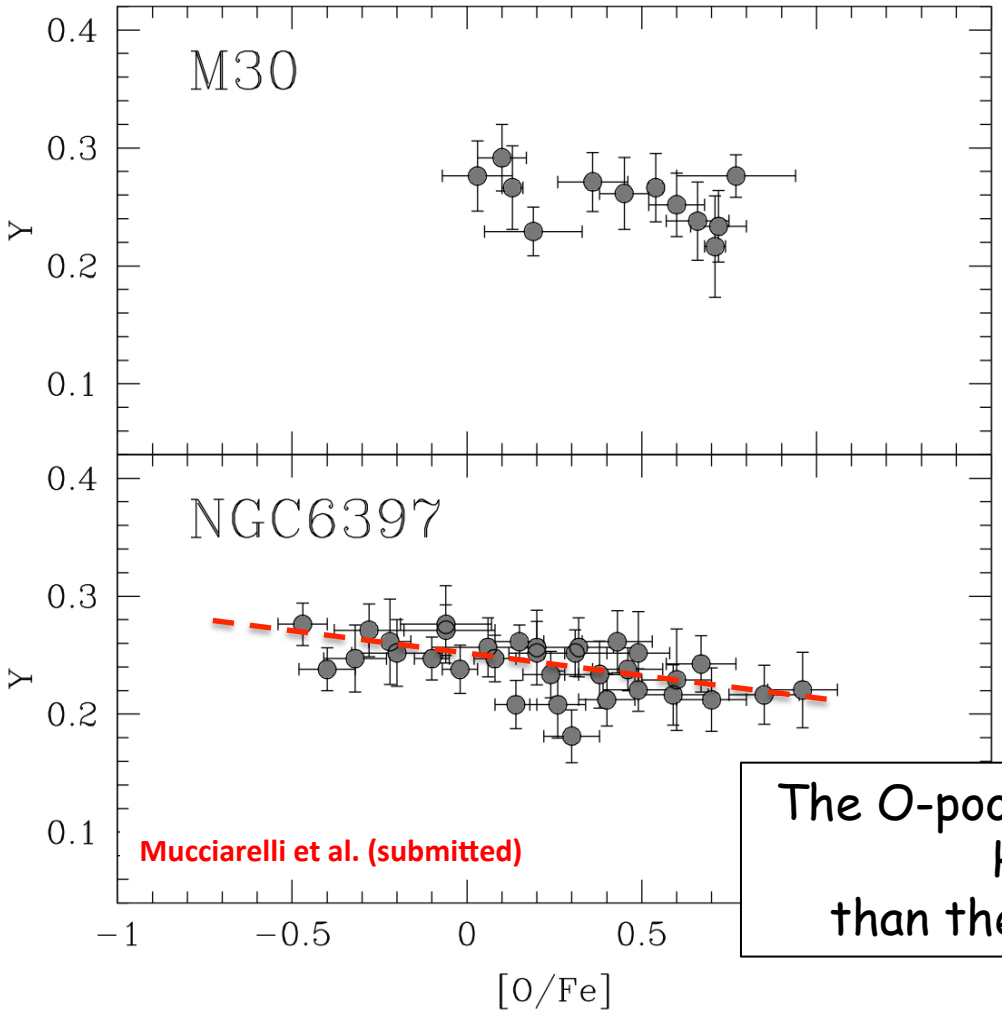
NGC6752 Villanova et al.(2009)



Helium in HB

Y = 0.24

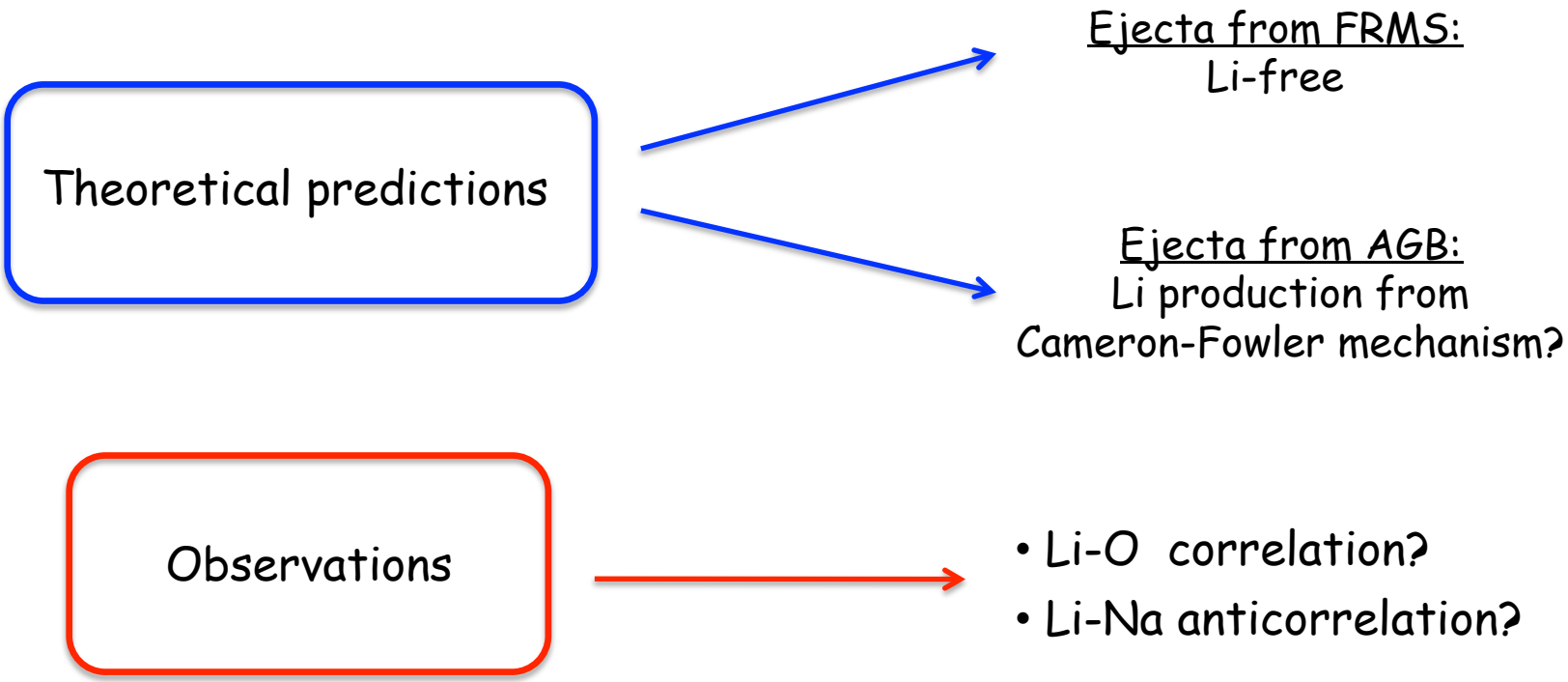
Y = 0.25



The O-poor stars are more He-rich than the O-rich stars.

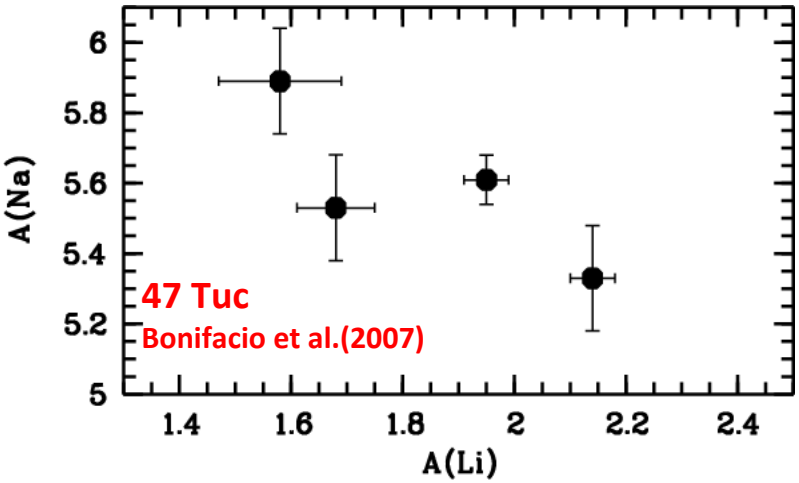
Lithium

- Destroyed at ~2.5 x 10^6 K
- It cannot survive at the T_{eff} of the hot H-burning
- Second generations stars should be depleted in Li

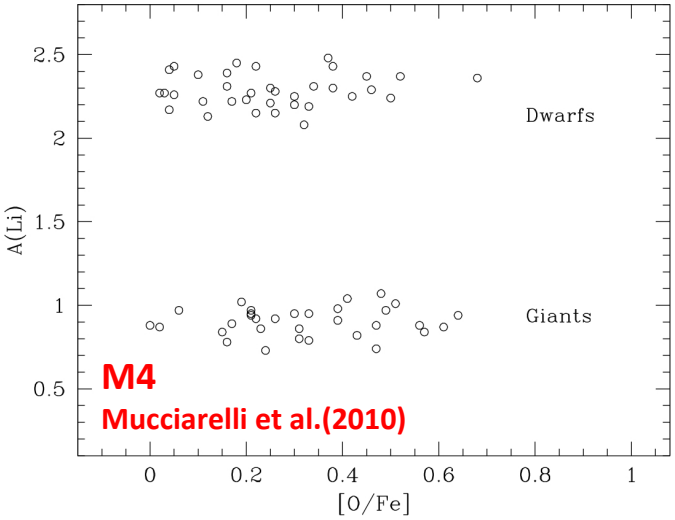


Lithium

Li-Na anticorrelation



NO Li-O correlation



Evidences of Li spread

Lind et al. 2011	NGC 6397
Shen et al. 2010	NGC 6752
Monaco et al. 2011	M4

No evidences of Li spread

D'Orazi et al. 2010	47Tuc
D'Orazi & Marino 2010	M4

No firm conclusion

Summaryzing …

- Genuine GCs are homogeneous in Fe
- Only 5 strange beasts
- Light elements (C, N, O, Na, Al …) vary in all the GCs
- … but also He !
- Li remains an open issue

Self-enrichment scenario:

Star formation within a short timescale
(but different chemical signatures among the stars)

Can we continue to use genuine GCs
as Simple Stellar Populations
(in spite of the chemical anomalies) ?

YES (but with some cautions)

(1) Homogeneous in [Fe/H] and
almost any other elements
(except for C, N, O, Na, Mg, Al)

Tracers of the chemical composition of the host galaxy

(2) Single age !!!
(the self-enrichment timescale
is much smaller than the GC age)

Age-metallicity Relation

(3) Integrated colors
(only U filters are heavily affected
by the chemical anomalies)

Unresolved GCs

Are the GCs strictly speaking SSP?

NO, but they have never been considered so

Are the GCs the simplest SSP available in the Universe?

YES, whatever complex their formation scenario is

NO GLOBULAR CLUSTERS
WERE HARMED IN THE
MAKING OF THIS TALK

The End