The quite complex "simple stellar populations" of Globular Clusters

Angela Bragaglia

INAF-Osservatorio Astronomico di Bologna

IAU Symp. 268 - Light elements in the Universe - Geneva - Nov 10 2009

Outline
(& conclusions)

I intend to present the following case:

- that GCs are quite complex stellar aggregates
- that this complexity is apparent from their CMDs (HB, SGB, MS)
- that it can also be deduced from their chemistry (CNO, Na-O)
- that the ”anomalies” are connected with the GC formation
- that the He content may be different from star-to-star
- that GCs self-pollution is modulated by their mass (but not exclusively)

GC ≠ SSP

Single Stellar Population

SSP : coeval, (initially) chemically homogeneous, single stars

SSP : described by age, composition (Y, Z), IMF

Best examples: star clusters

(see Renzini & Buzzoni 1986)

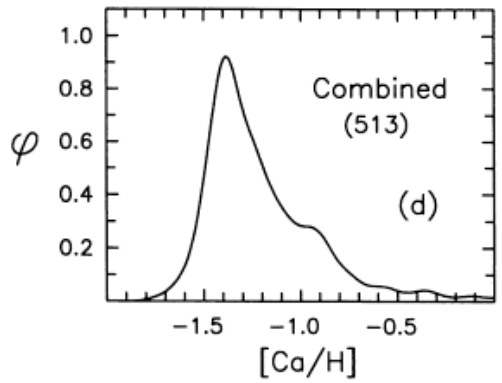
but :

- There are binaries
- Not all stars have same initial chemical composition (Z and/or Y)
- Not all stars are strictly coeval

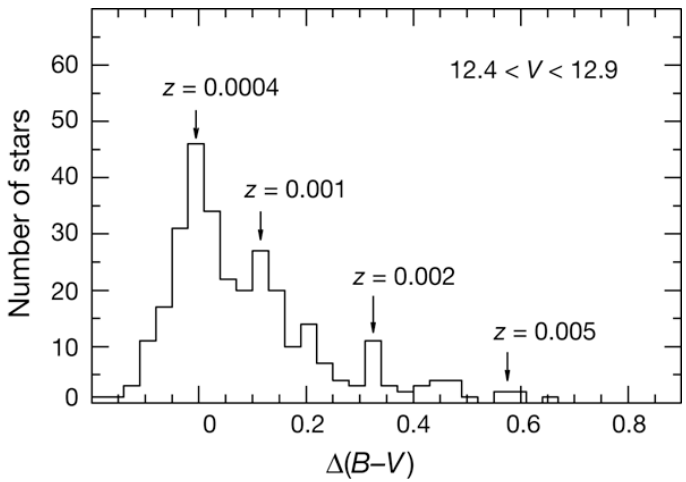
Not all GCs were created simple

…from the "classical" ω **Cen** …

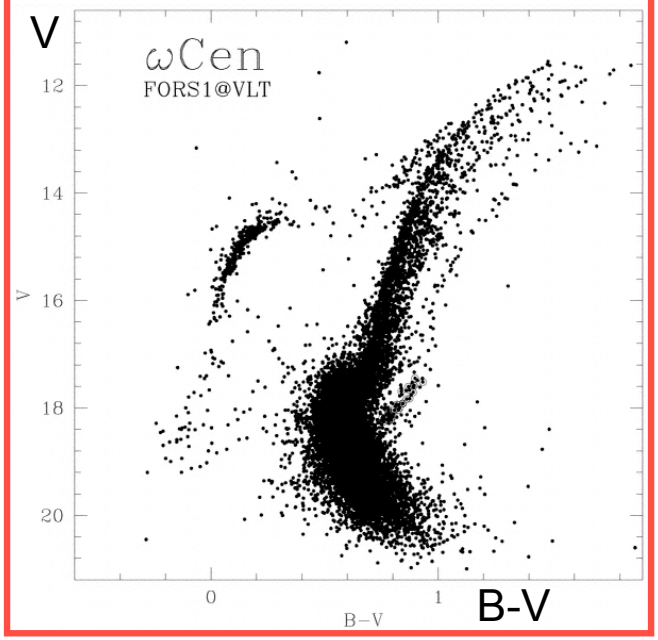
Norris et al. 1996



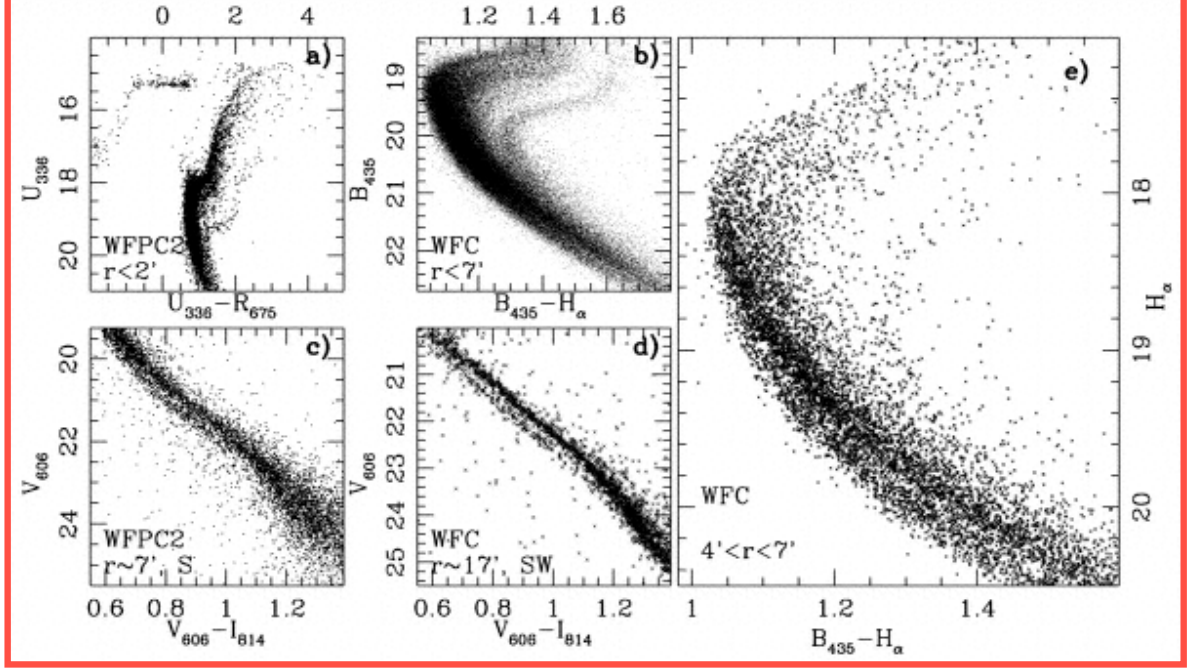
Lee et al. 1999



Ferraro et al. 2004

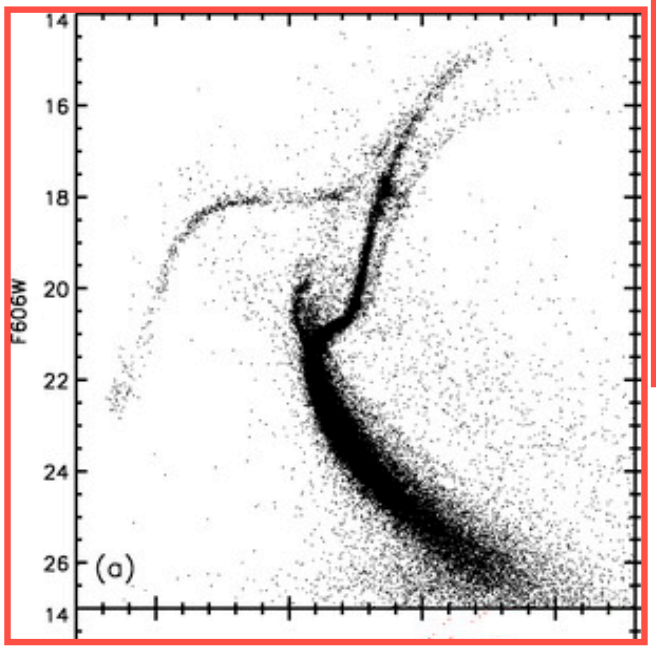


Bedin et al. 2004

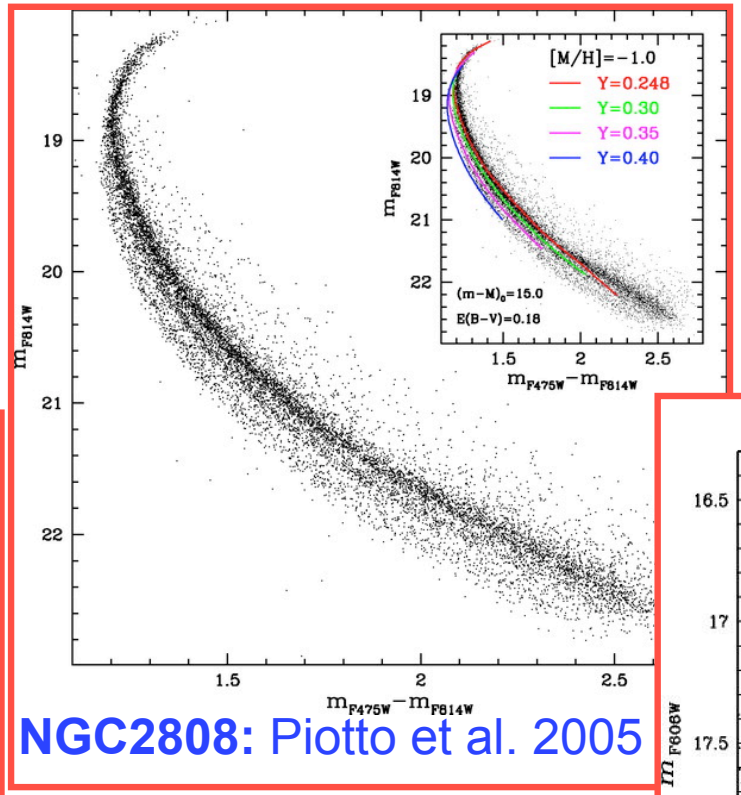


Not all GCs were created simple

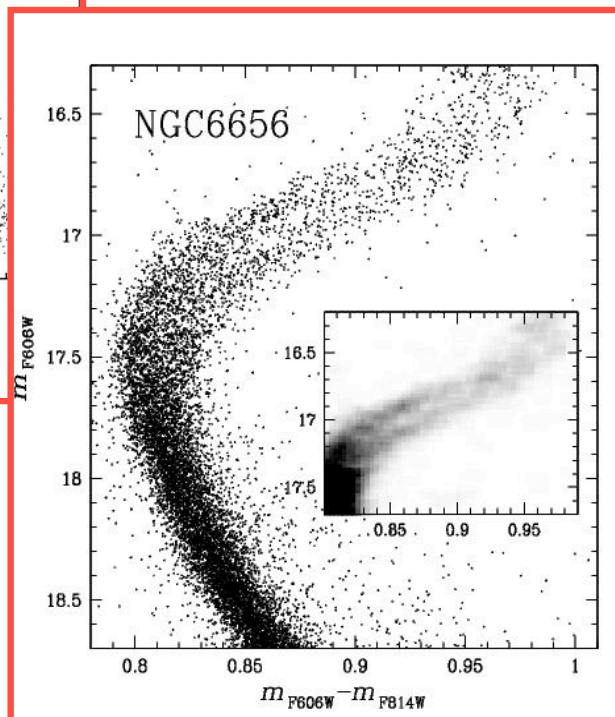
…to M54, NGC 2808, M22, etc …



M54: Siegel et al. 2007



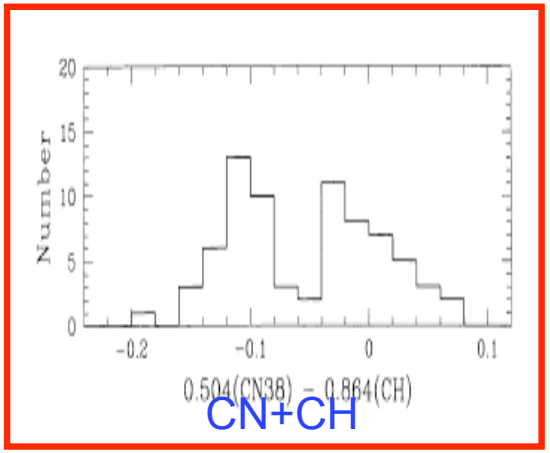
NGC2808: Piotto et al. 2005



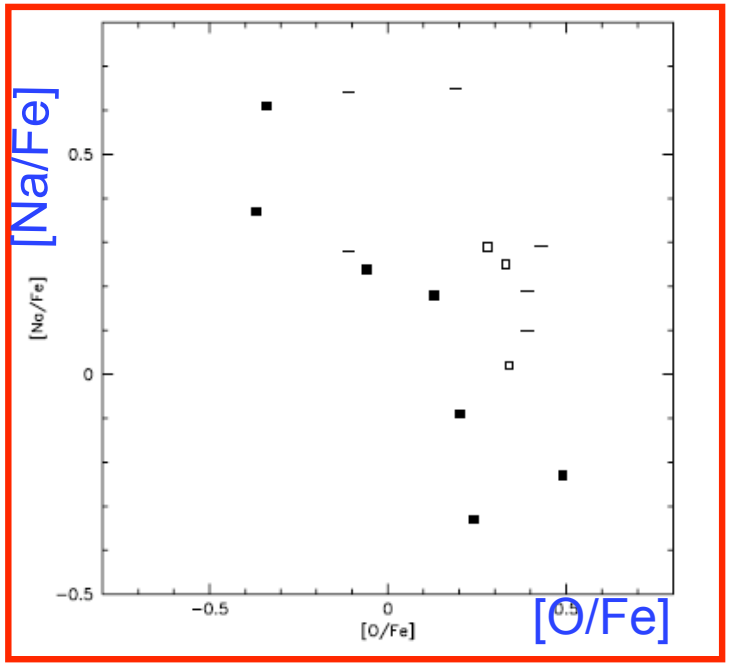
M22: courtesy A.Milone

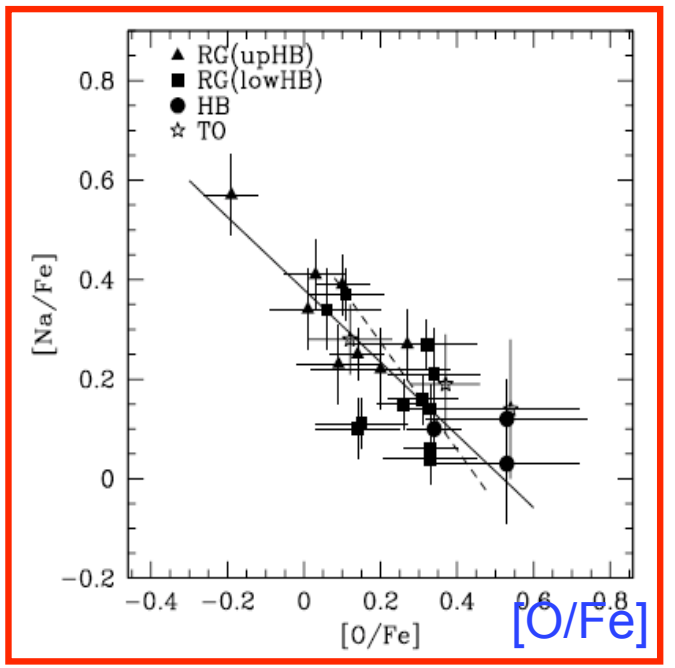
Not all stars were created equal

(…with the same initial chemical composition…)



CN+CH





Cannon et al. (1998) --- Gratton et al. (2001) --- Ramirez & Cohen (2002)
47 Tuc NGC6752 M71

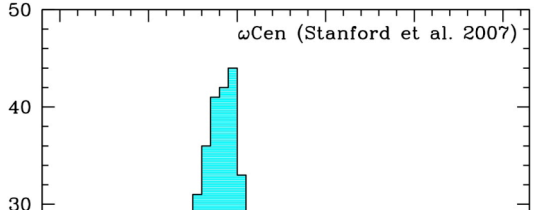
TO, SGB & lower RGB stars show Na-O anticorrelation

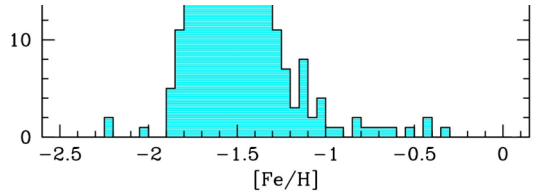
⇒ no (important) extra-mixing, but ORIGINAL difference

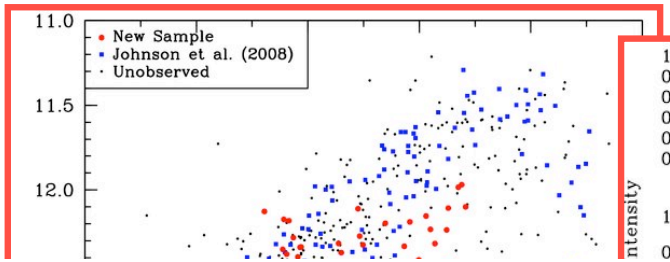
⇒ **multiple populations in GCs**

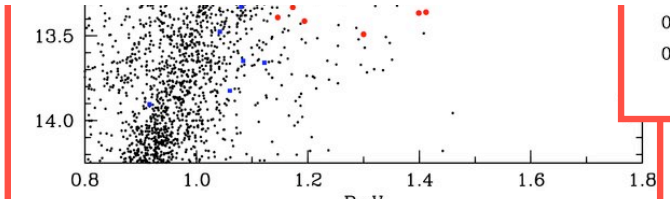
[Fe/H]: ω Cen & M22 (& M54…)

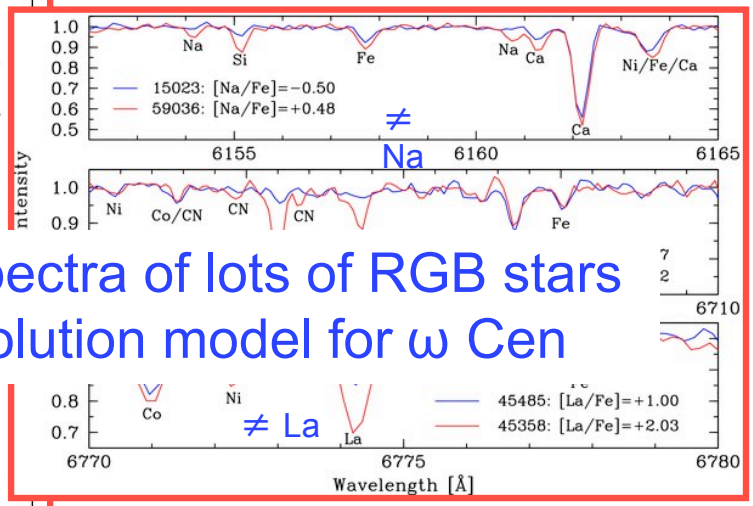
Stanford et al. 2007







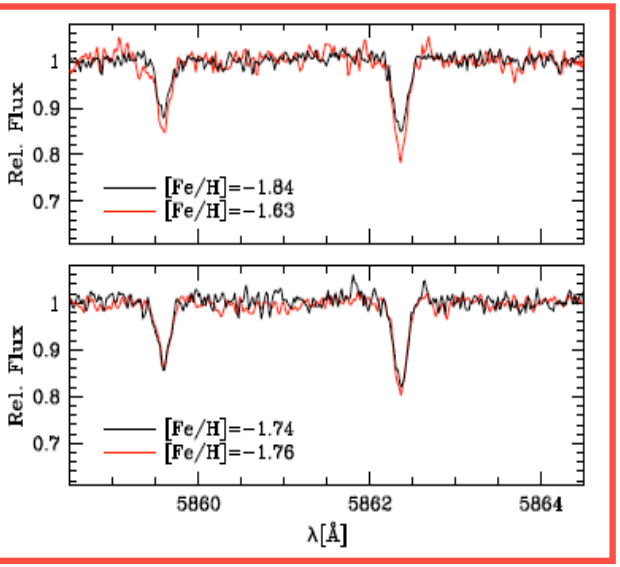


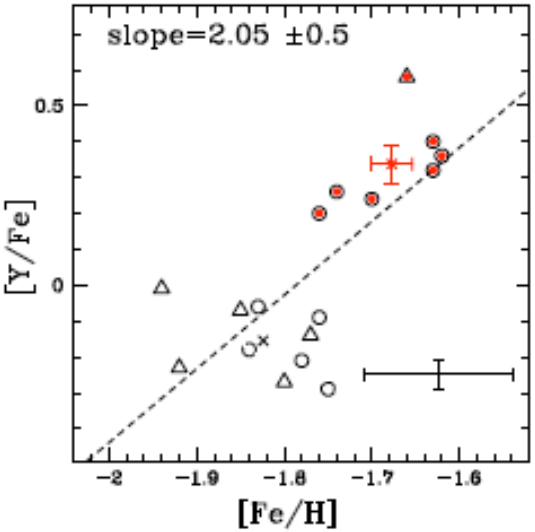


See posters by Marino et al. on new high-res spectra of lots of RGB stars & Romano et al. on a chemical evolution model for ω Cen

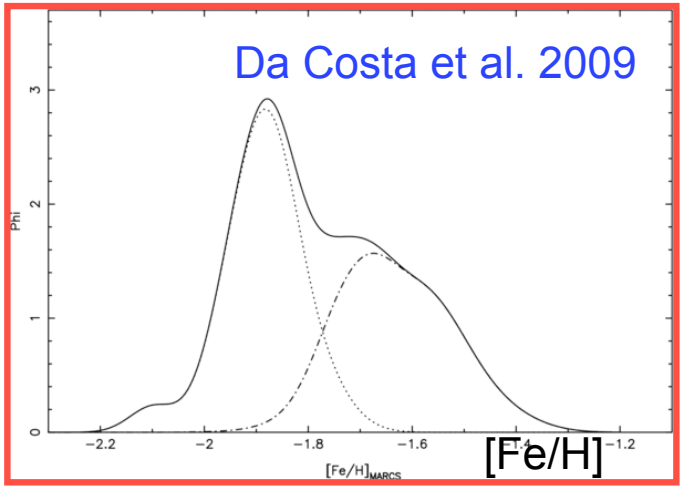
Johnson et al. 2009

ω Cen



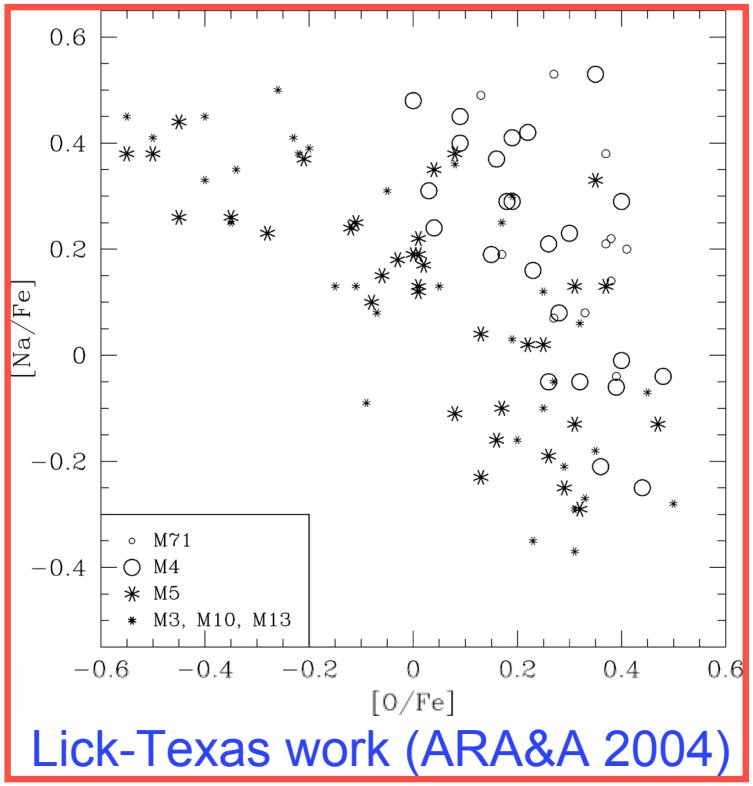


Marino et al. 2009

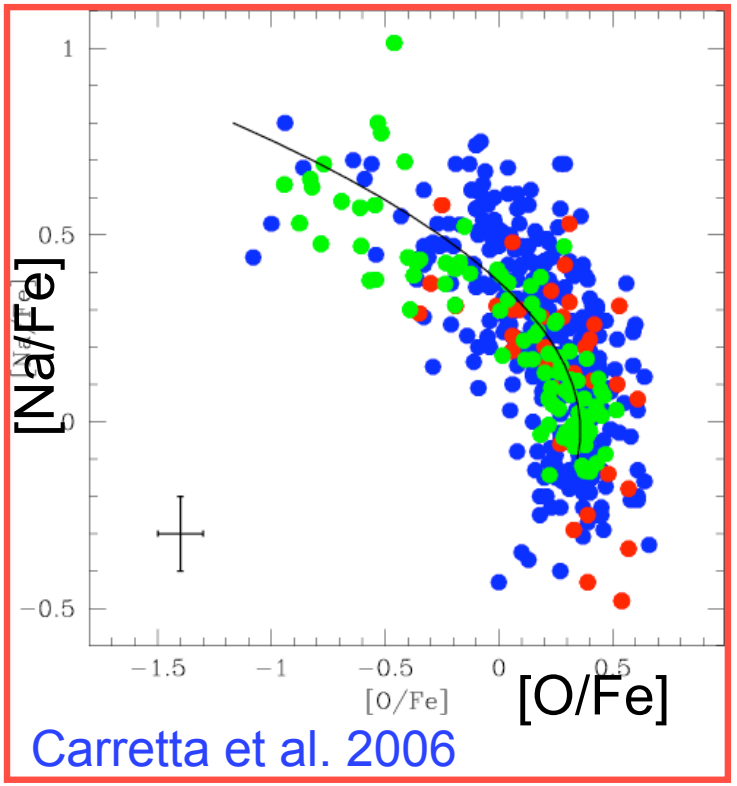


M22

Na-O anticorrelation



Lick-Texas work (ARA&A 2004)

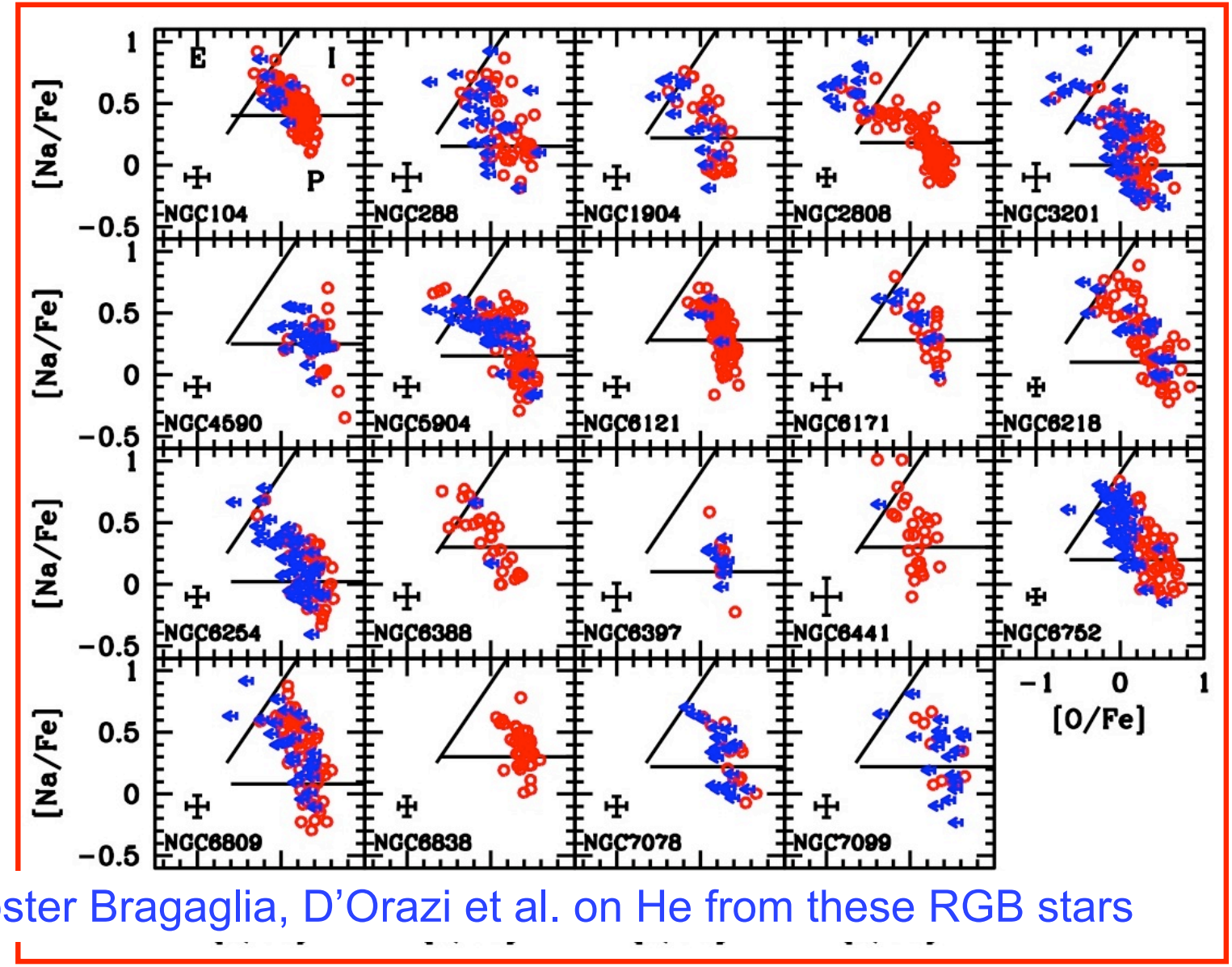


Carretta et al. 2006

- RGB
- NGC2808
- TO & SGB

Na-O anticorrelation

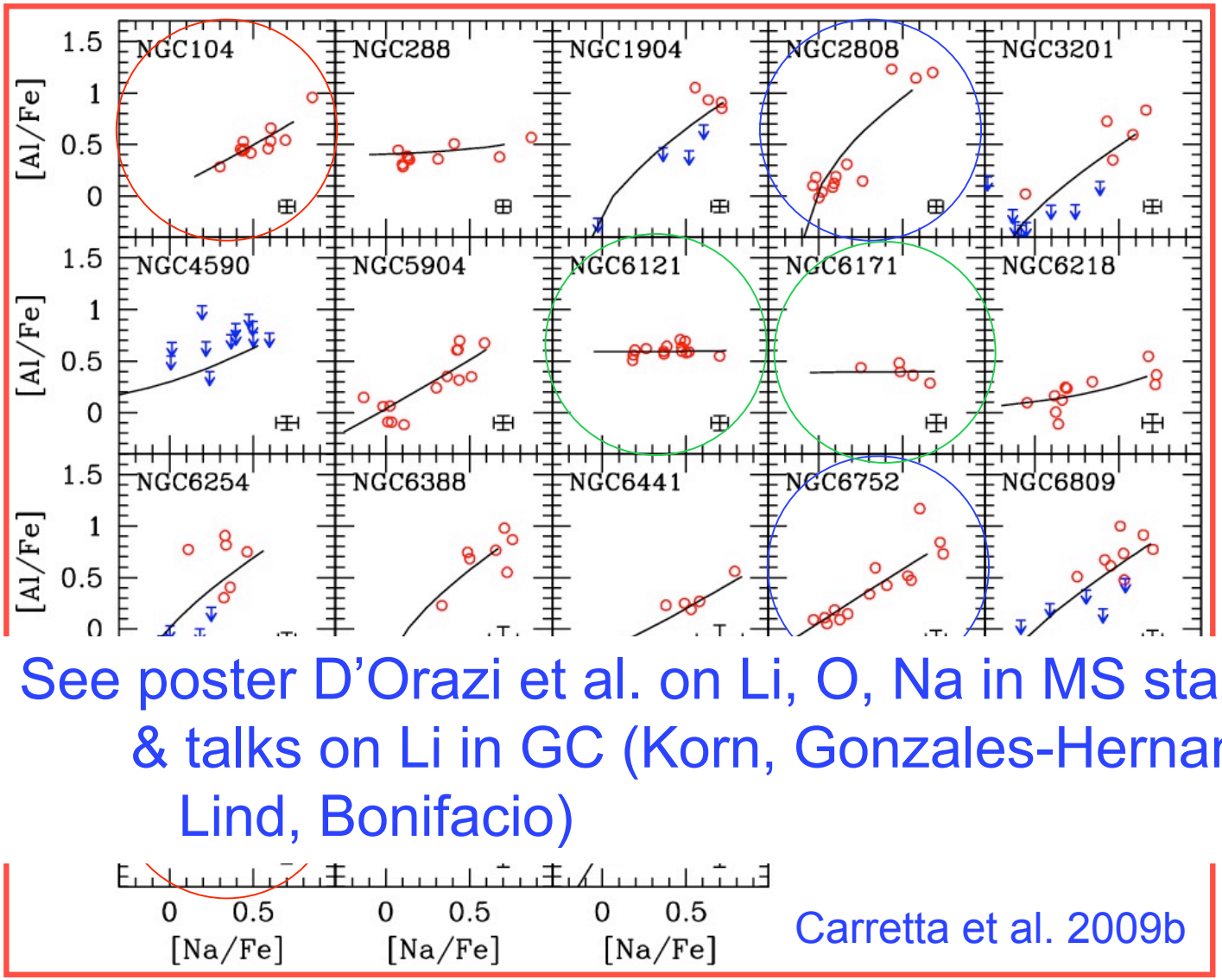
Carretta et al. 2006; 2007a,b,c ; 2009a,b; Gratton et al. 2006; 2007



See poster Bragaglia, D'Orazi et al. on He from these RGB stars

Other (anti)correlations

Mg-Al (anticorr.) ; Mg-Si (corr.) ; Al-Na (corr. -but Al …)



Carretta et al. 2009b

Different shapes

⇩

≠ polluters

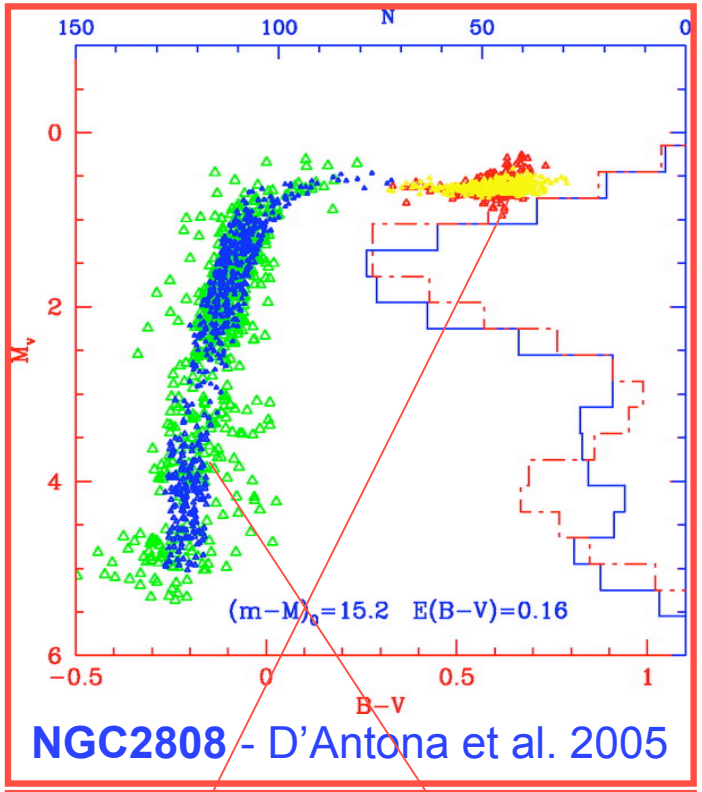
(all H-burning, but ≠ Teff, i.e. ≠ mass)

See poster D'Orazi et al. on Li, O, Na in MS stars in 47 Tuc & talks on Li in GC (Korn, Gonzales-Hernandez, Lind, Bonifacio)

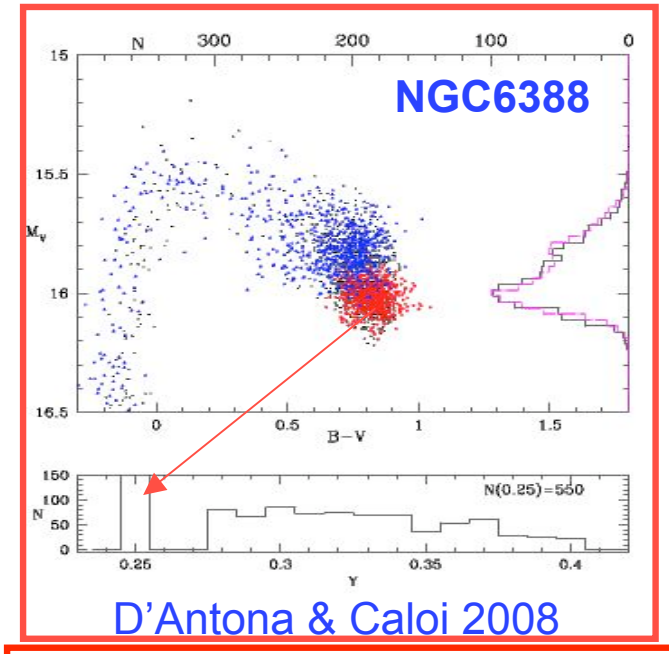
He and the HB (a)

higher Y ⇒
brighter HB
bluer HB

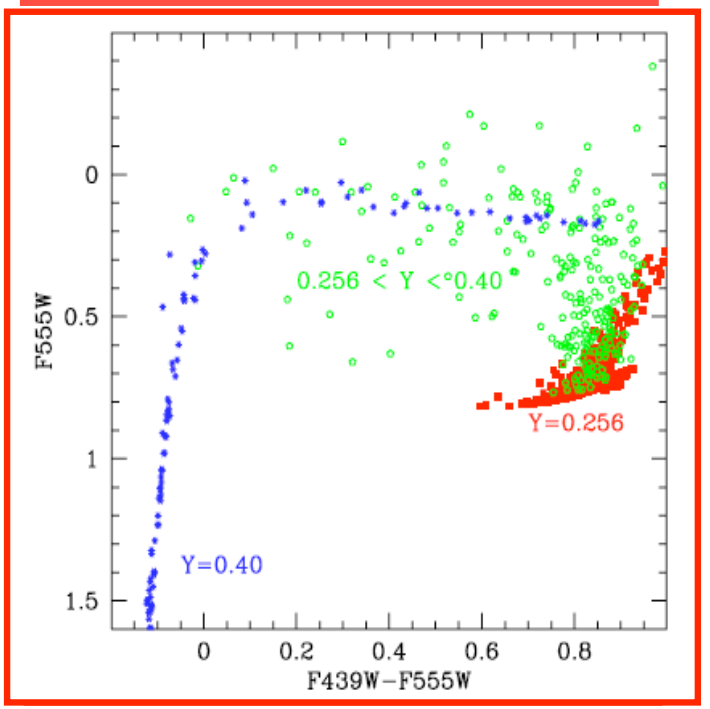
Proposed link between the broad MS and the HB:
different Y



NGC2808 - D'Antona et al. 2005

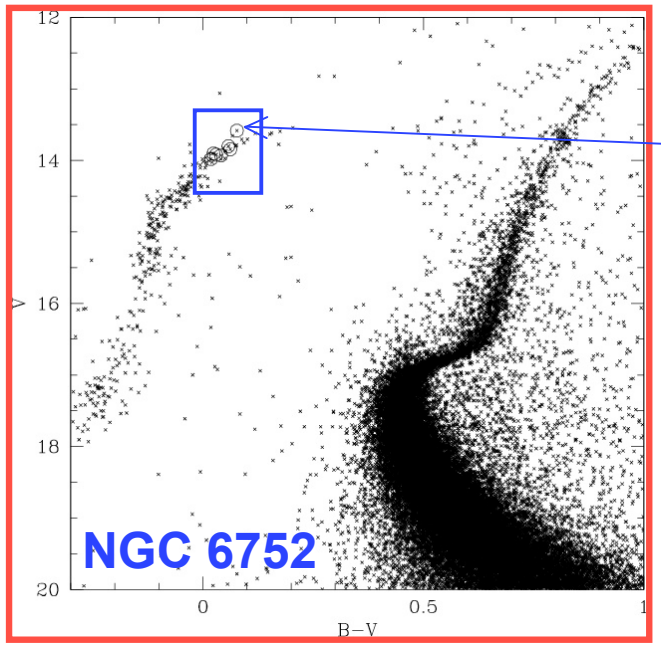


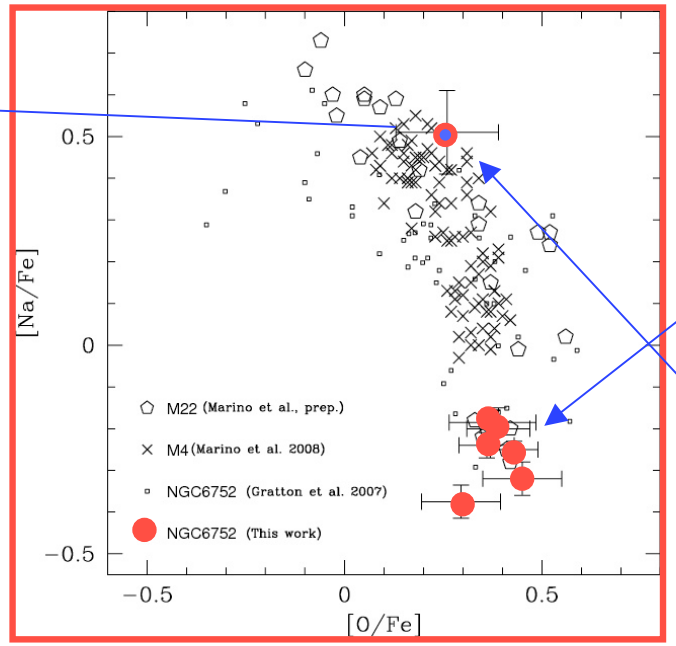
D'Antona & Caloi 2008



He and the HB (b)

Villanova, Piotto, Gratton 2009 : direct He measure in HB stars



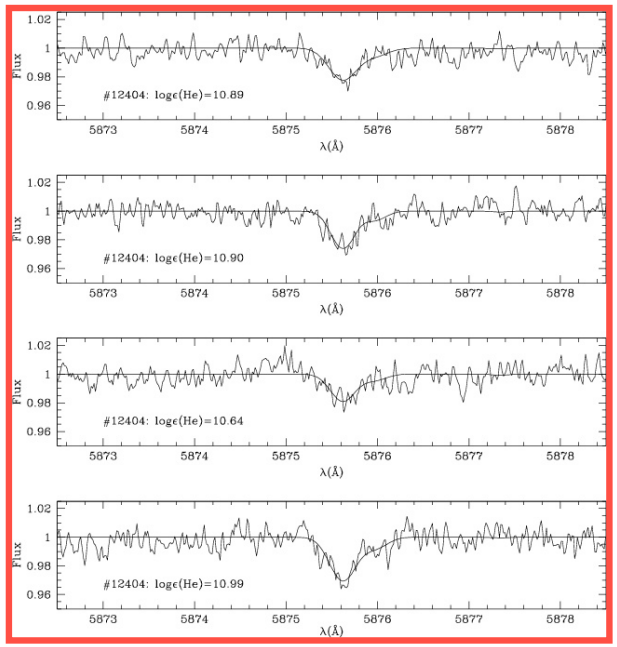


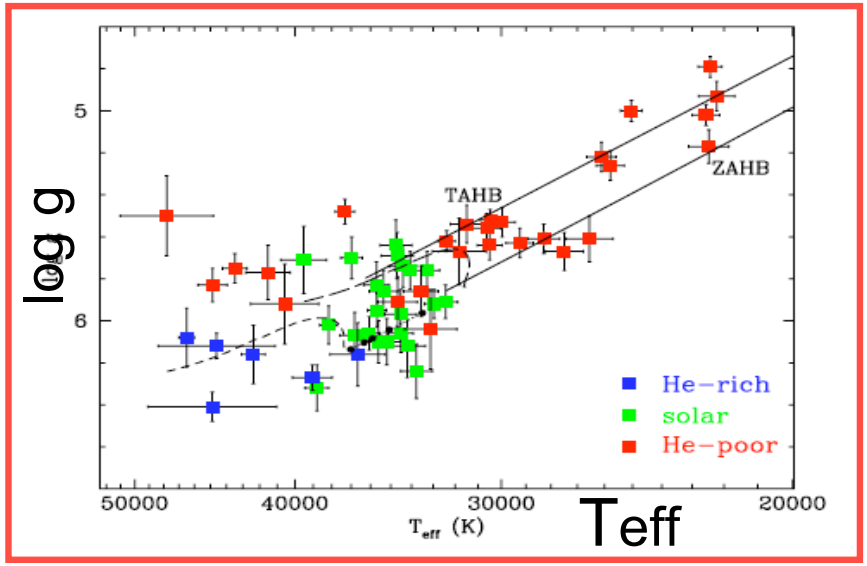
<Y>=0.245 ± 0.012
4 stars O-rich

No measure for O-poor star : not conclusive

See Moheler et al 2007 for ω Cen (Y-enrich. vs late He-flashers)

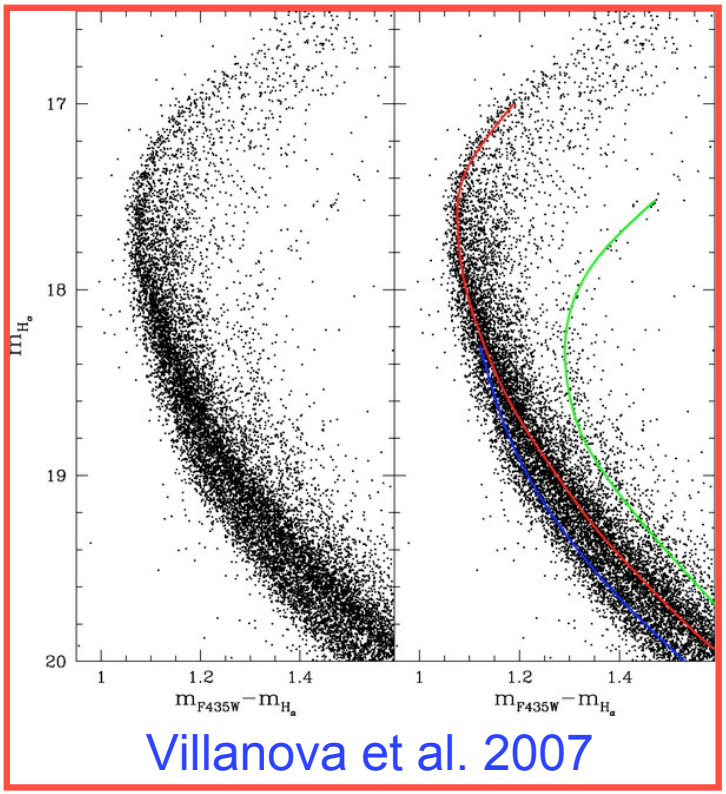
2%





He & multiple MS (a)

ω Cen



Villanova et al. 2007

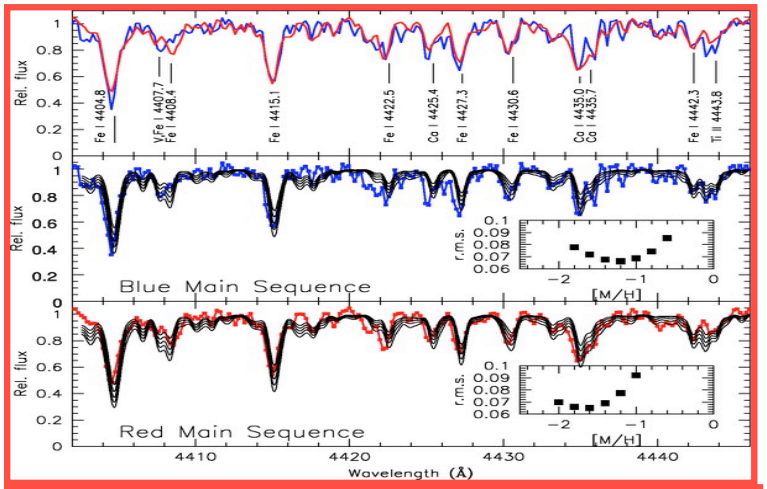
FLAMES@VLT
LR2,12 hrs
17 rMS ★
17 bMS ★

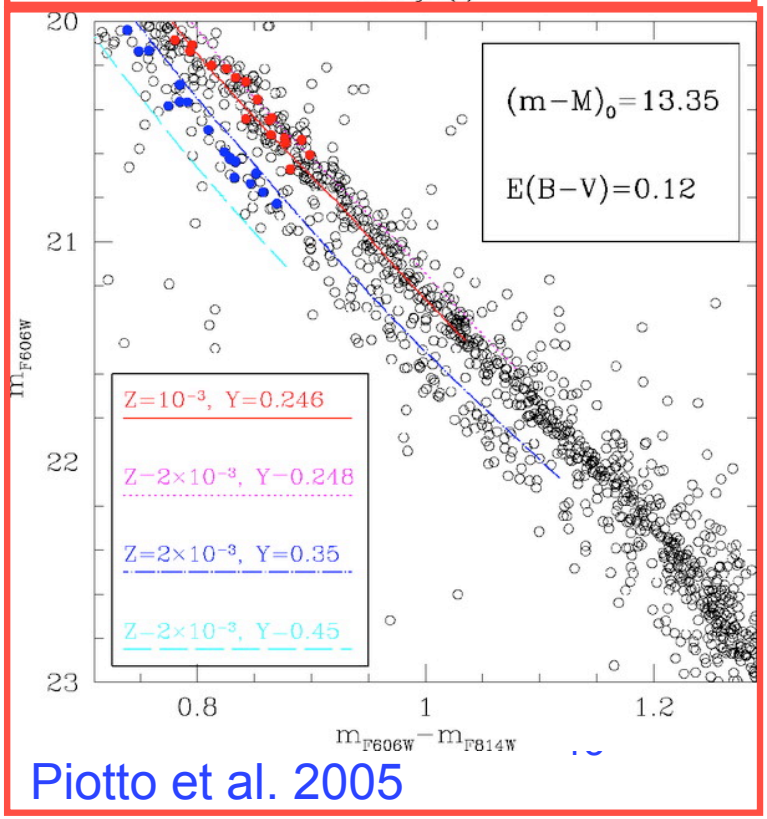
bMS more metal-rich (0.3±0.2 dex)
bMS : -1.26
rMS : -1.57

rMS : $Z=10^{-3}$ $Y=0.246$
bMS : $Z=2\times10^{-3}$ $Y\approx0.38$

NB Δ[Fe/H] *measured*, ΔY *inferred*

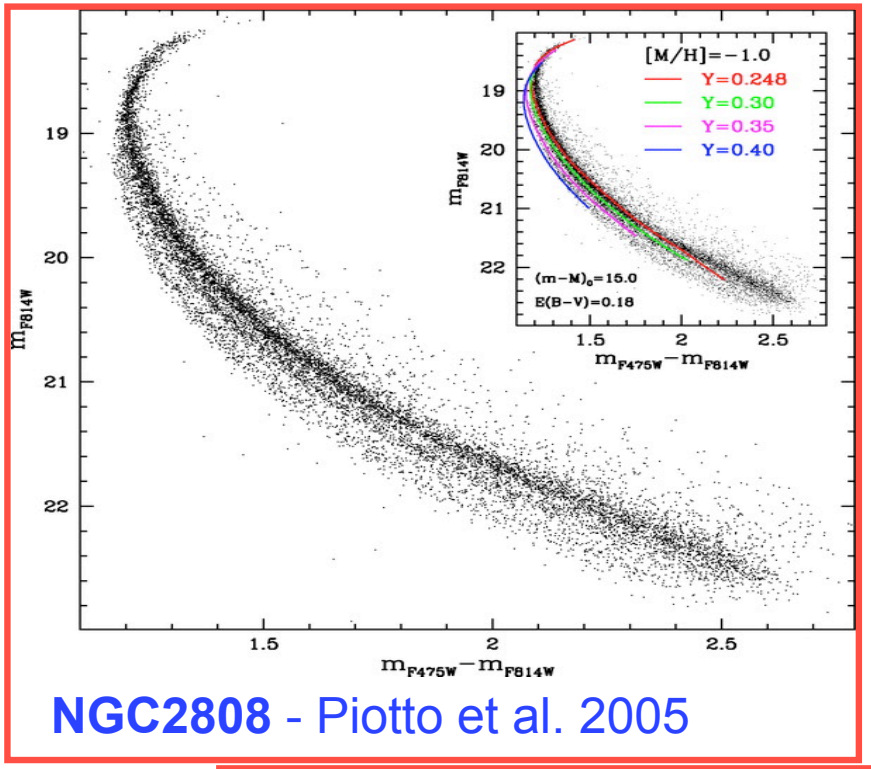
Confirmed by new multiepoch ACS data (members)





Piotto et al. 2005

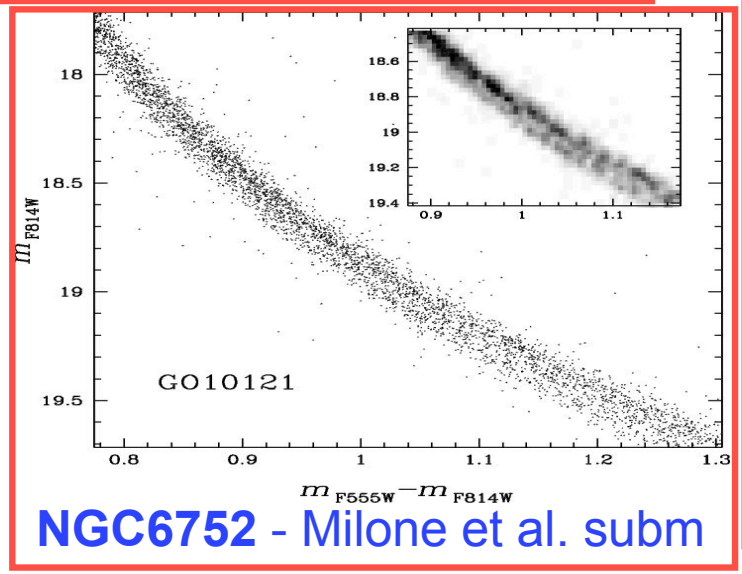
He & multiple MS (b)



NGC2808 - Piotto et al. 2005

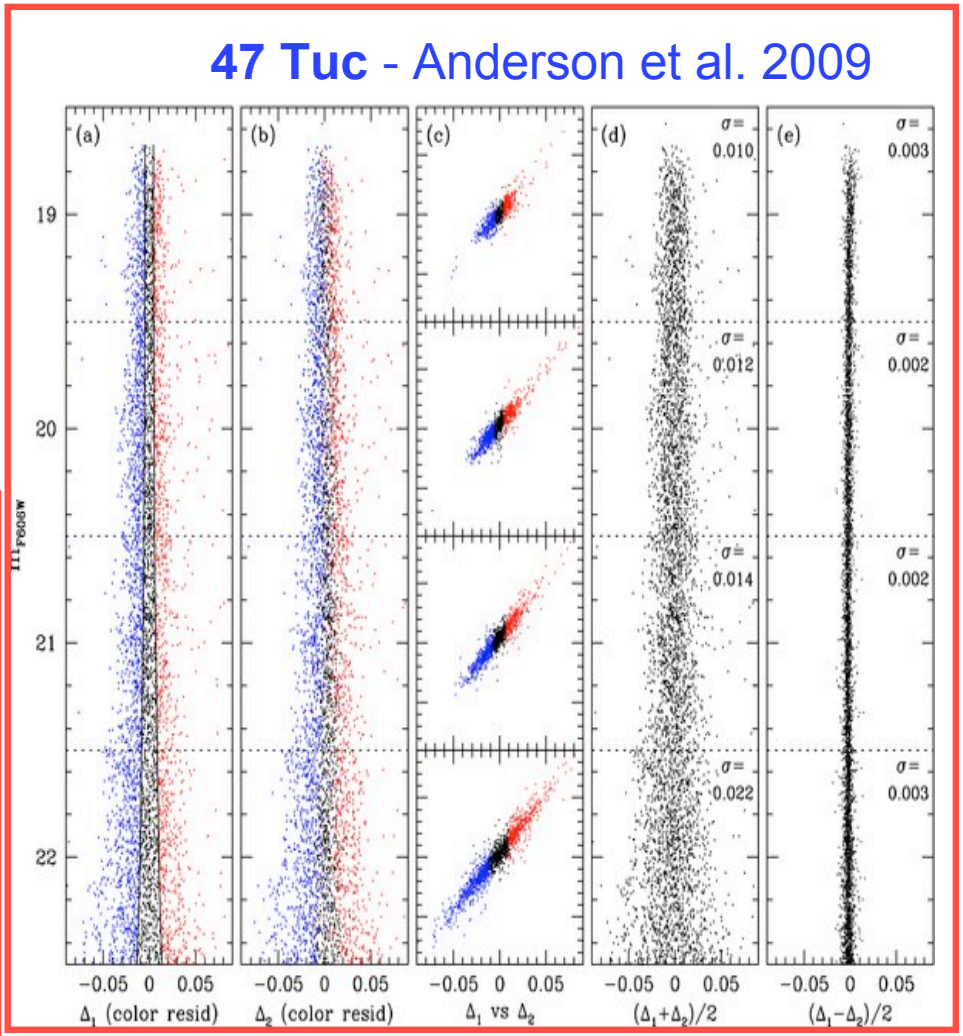
⇐ **Y=0.248**
Y=0.30
Y=0.37 (0.35-0.40)

} no age difference



NGC6752 - Milone et al. subm

47 Tuc - Anderson et al. 2009



NGC 2808

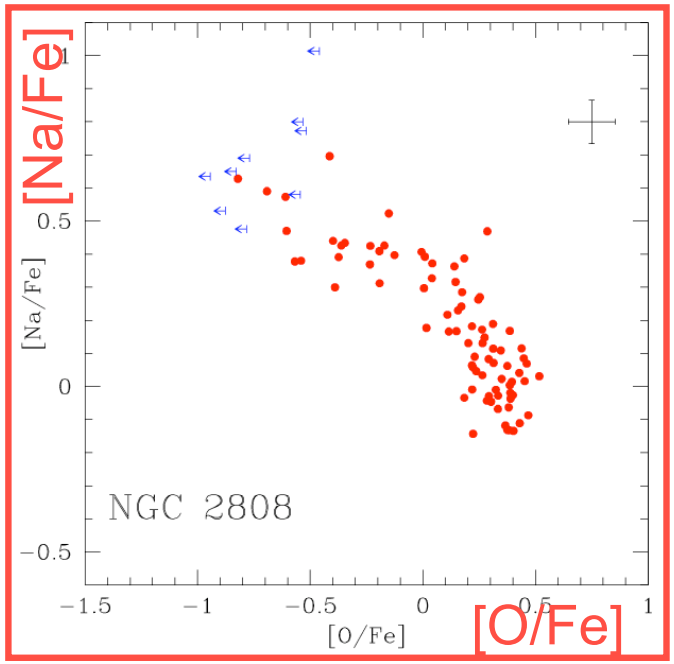
Remember:

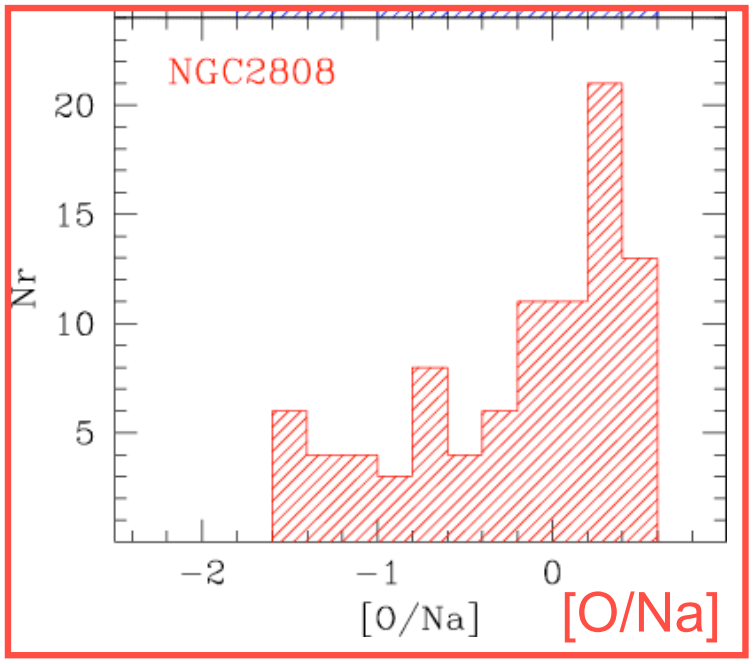
- complex HB (3 main groups)
- triple MS

But also:

- very extended Na-O anticorrelation (3 peaks?)

D'Antona et al. 2005, Piotto et al. 2007 : all connected ?



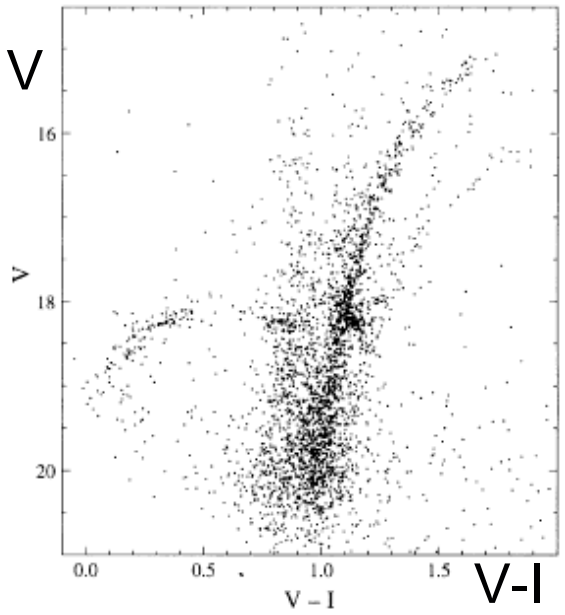


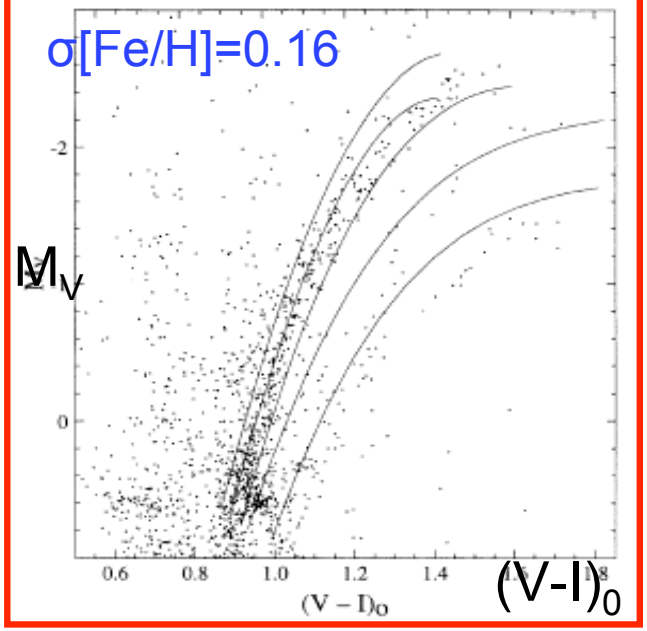
O-poor
(& Na-rich
& N-rich)
⇒ He-rich

Carretta et al. 2006

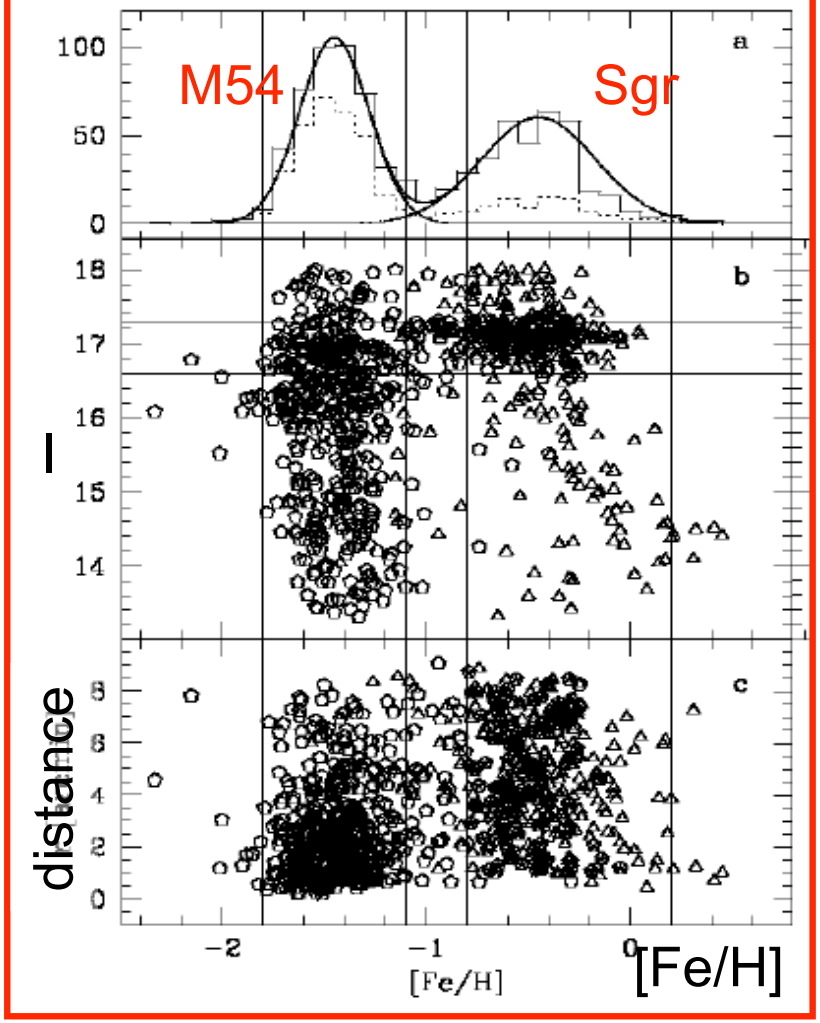
M54 (a)

Sarajedini & Layden 1995



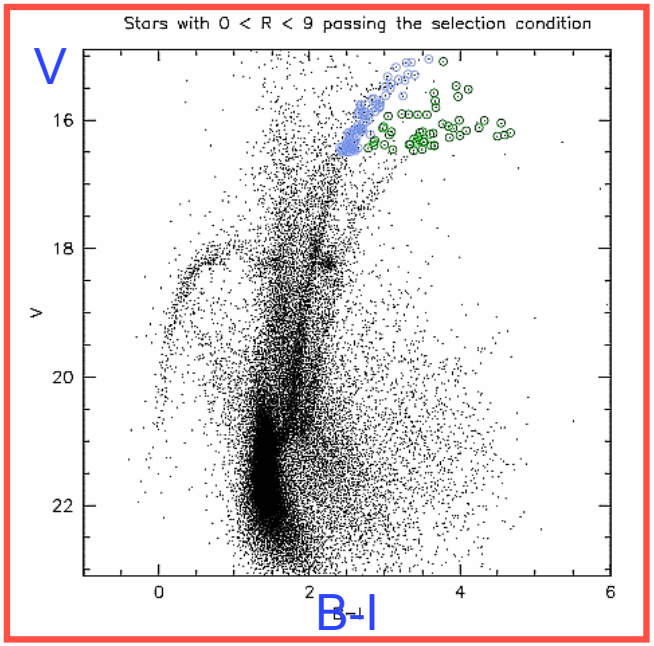


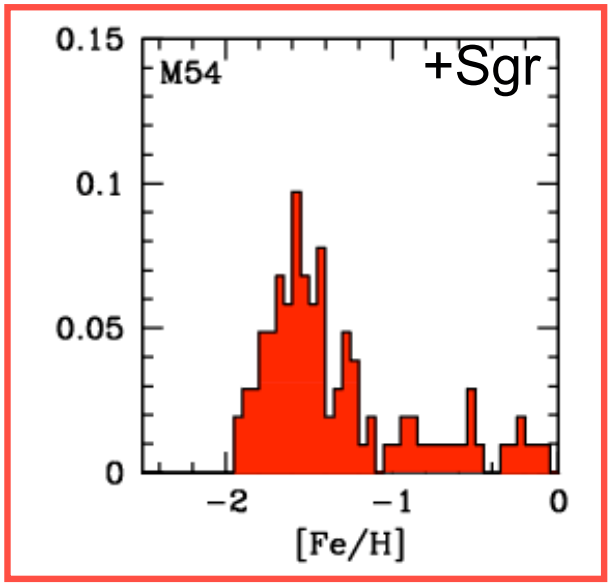
Bellazzini et al. 2008



CaT spectra, DEIMOS@Keck,
420 ★ (M54) & 320 ★ (Sgr)
met. rms (M54) = 0.17 dex

M54 (b)





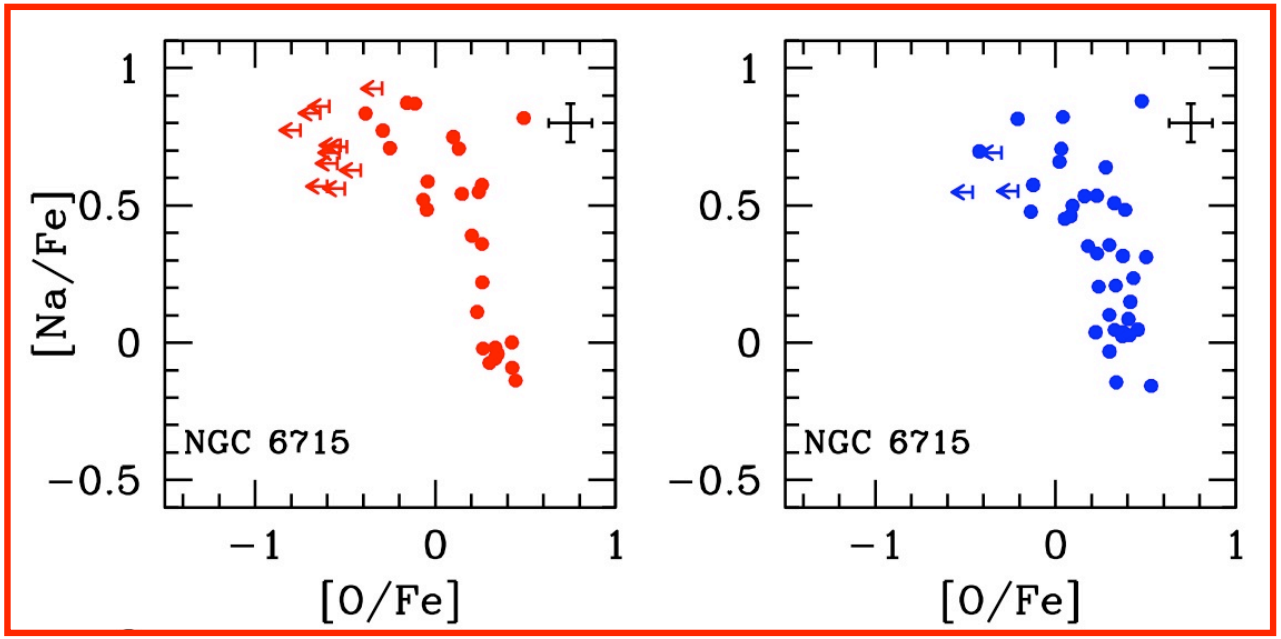
FLAMES@VLT

<[Fe/H>=-1.56 (**M54**)
rms=0.19 dex (76 ★)
error=0.05 dex
(confirming results, e.g.
Bellazzini et al. 2008)

<[Fe/H>=-0.62 (**Sgr**)
rms=0.35 dex (27 ★)

[Fe/H]>-1.56

IQR=1.20
P=24± 8%
I=32 ± 10%
E=43 ±11%



[Fe/H]≤-1.56

IQR=0.78
P=31± 9%
I=59 ± 12%
E=10 ± 5%

Carretta et al. in prep.

All creatures great and small

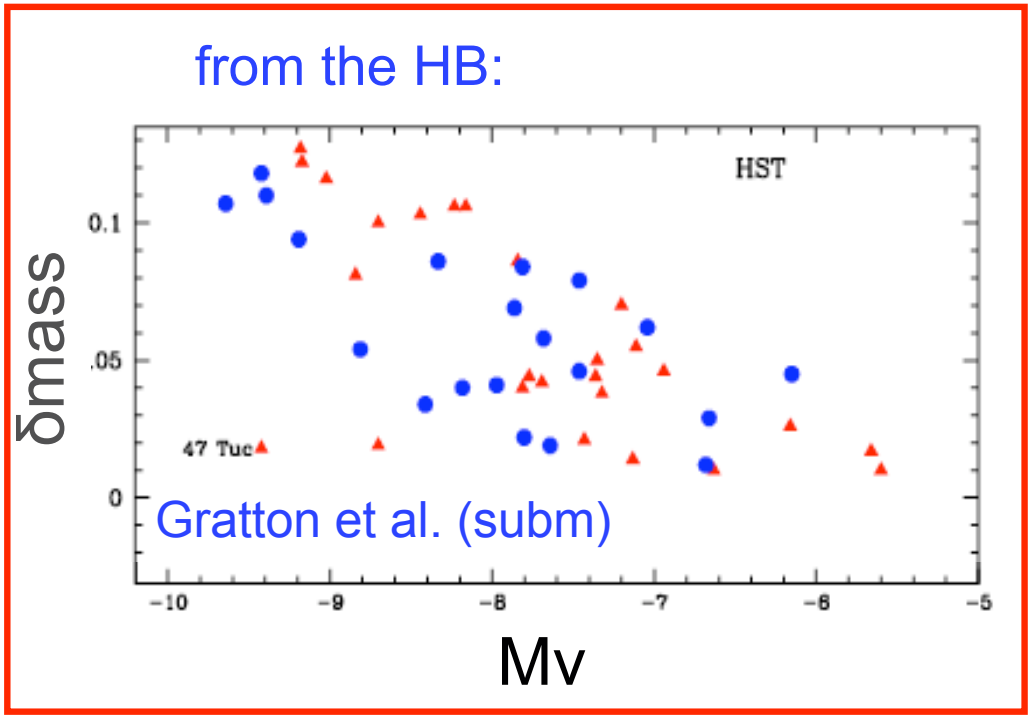
Unambiguous (photometric) evidence of MPs in :
ω Cen, NGC2808, M54, NGC6388, 47 Tuc, NGC1851, M22, NGC6752, …

… high-mass …

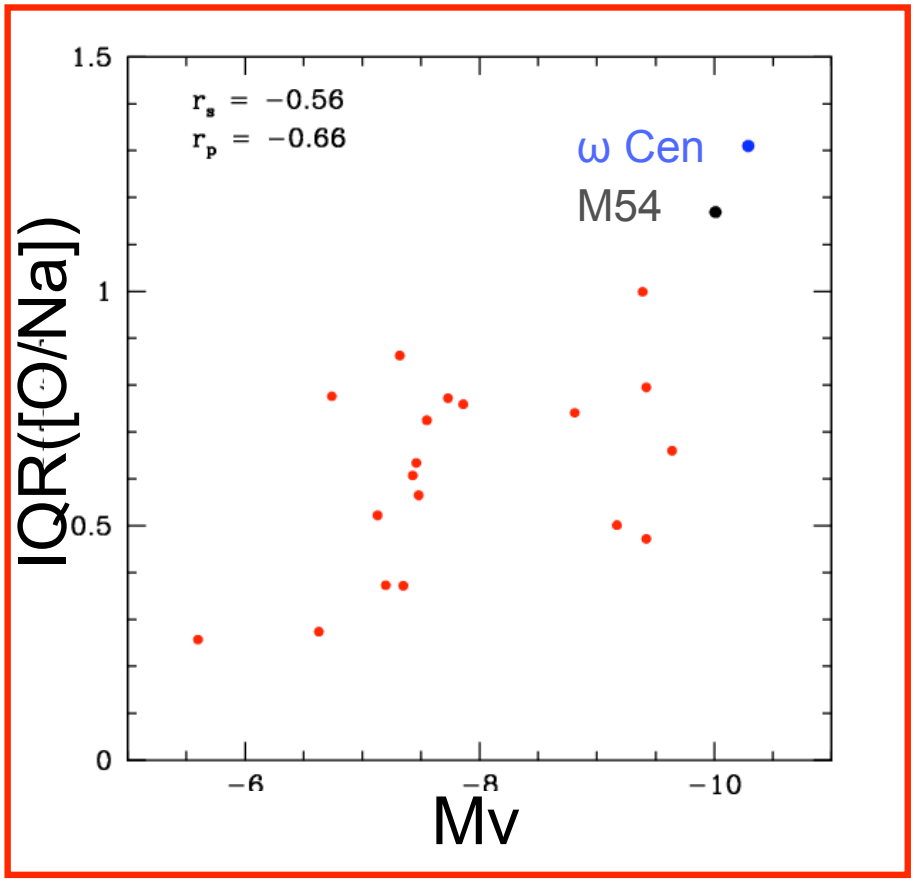
Unambiguous (spectroscopic) evidence of MP in all clusters studied

… intrinsic property …

from the HB:



Gratton et al. (subm)



… and mass is not all…

All creatures great and small

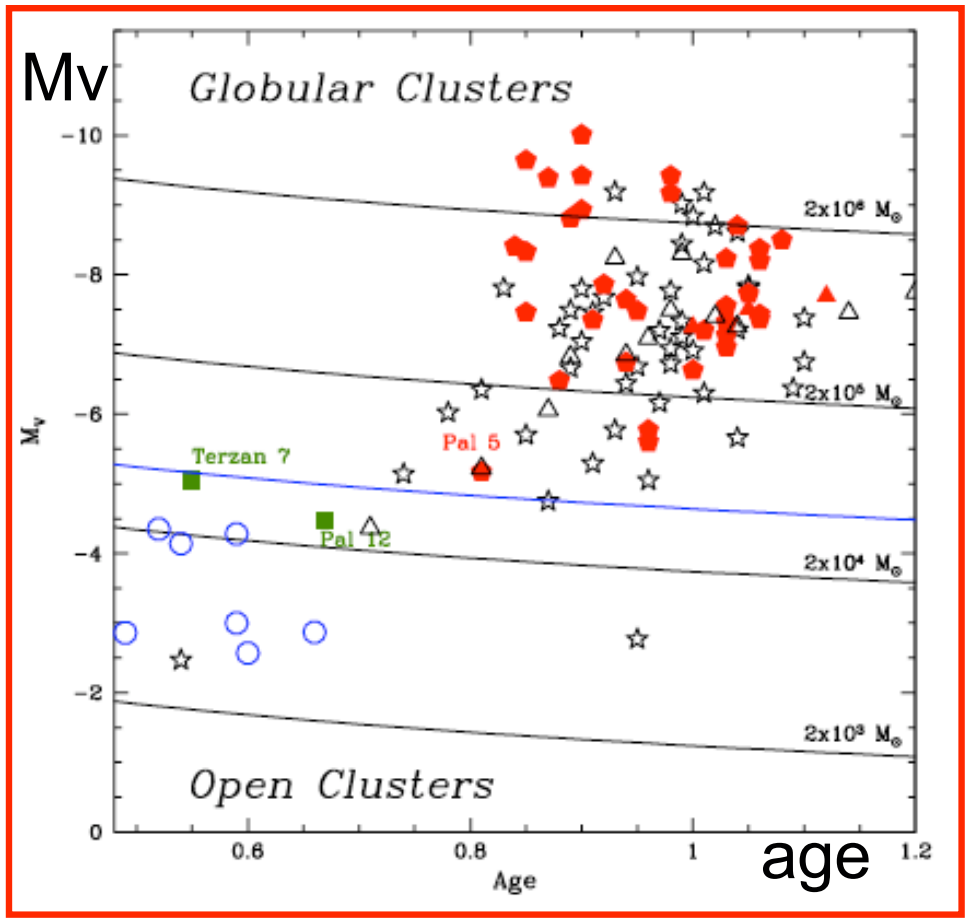
Unambiguous (photometric) evidence of MPs in :

ω Cen, NGC2808, M54, NGC6388, 47 Tuc, NGC1851, M22, NGC6752, …

… high-mass …

Unambiguous (spectroscopic) evidence of MP in all clusters studied

… intrinsic property …

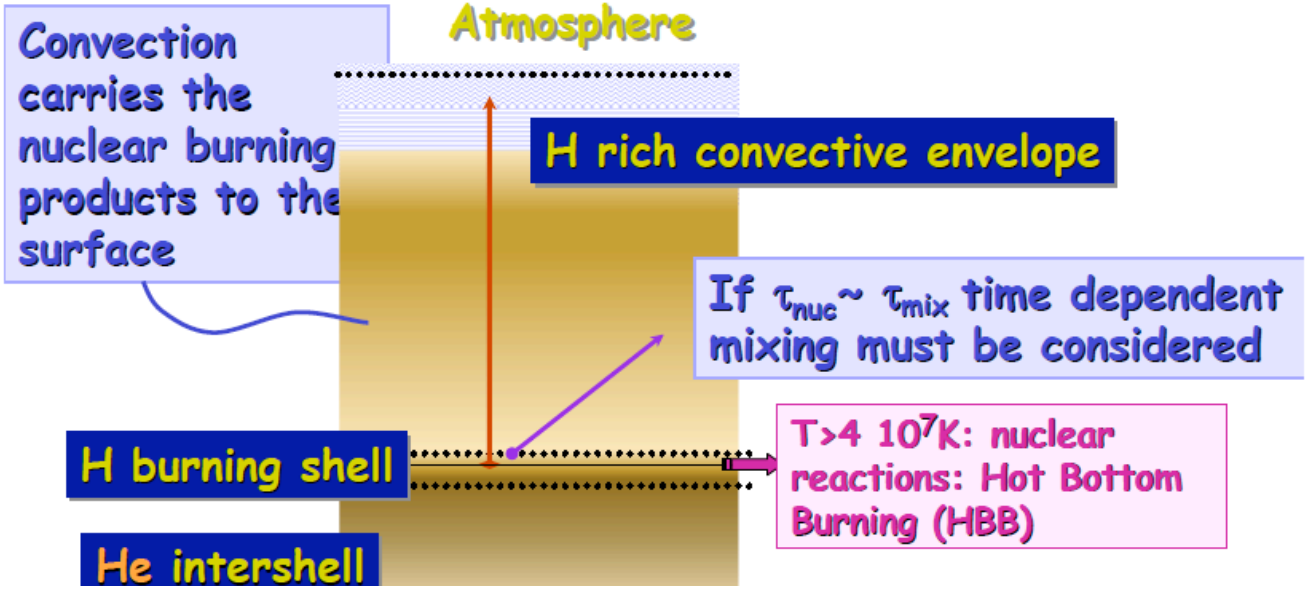


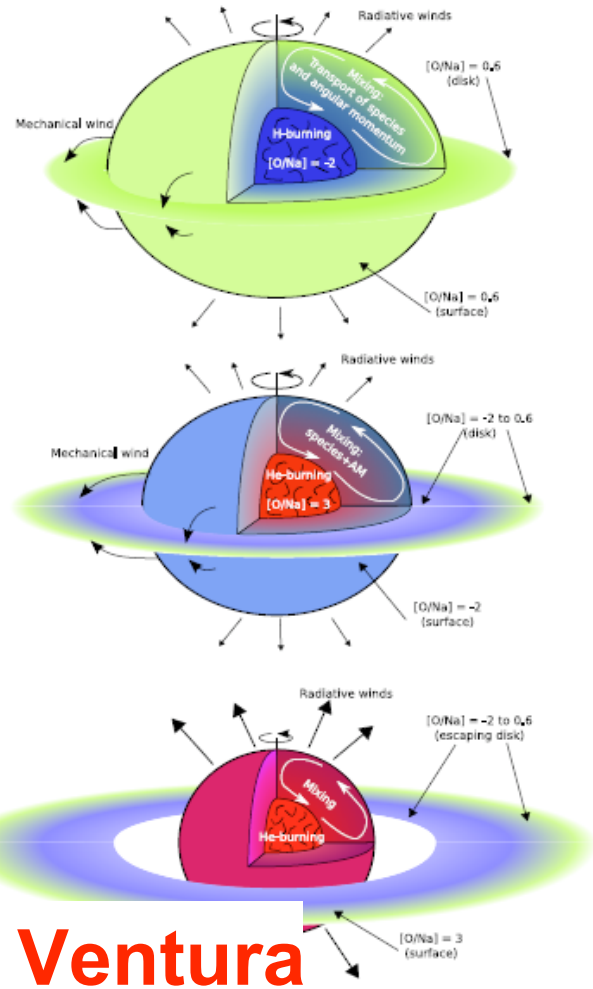
GCs ⇔ Na-O

Carretta et al. 2009d (submitted)

If only they could talk

Which are the polluters ? most promising candidates :
(massive) AGB or FRMS





See next talks by T. Decressin & P. Ventura to hear more on the models

Outline
(& conclusions)

I believe to have convincingly presented the case:

- that GCs are quite complex stellar aggregates
- that this complexity is apparent from their CMDs (HB, SGB, MS)
- that it can also be deduced from their chemistry (CNO, Na-O)
- that the ”anomalies” are connected with the GC formation
- that the He content may be different from star-to-star
- that GCs self-pollution is modulated by their mass (but not exclusively)

THANK YOU