The progenitors of the very hot Horizontal Branch and "blue hook" stars in Globular Clusters

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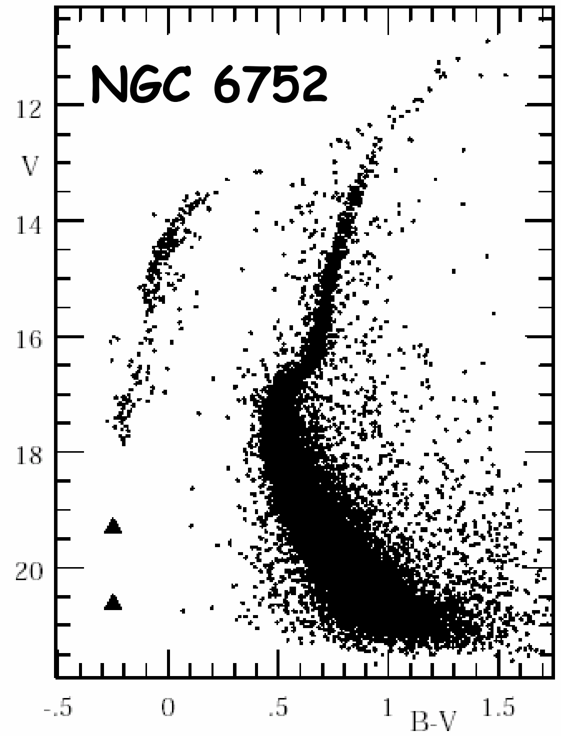
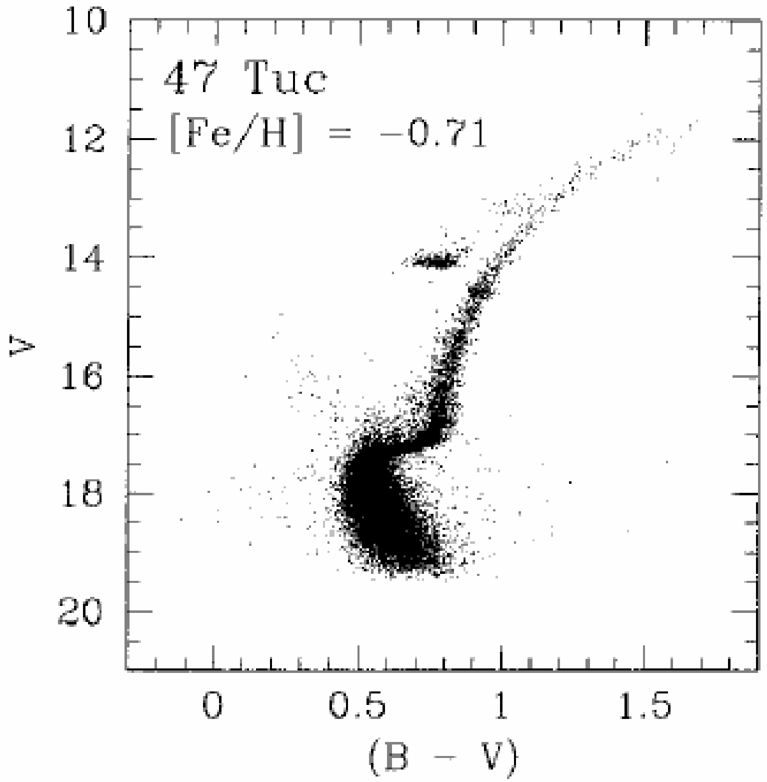
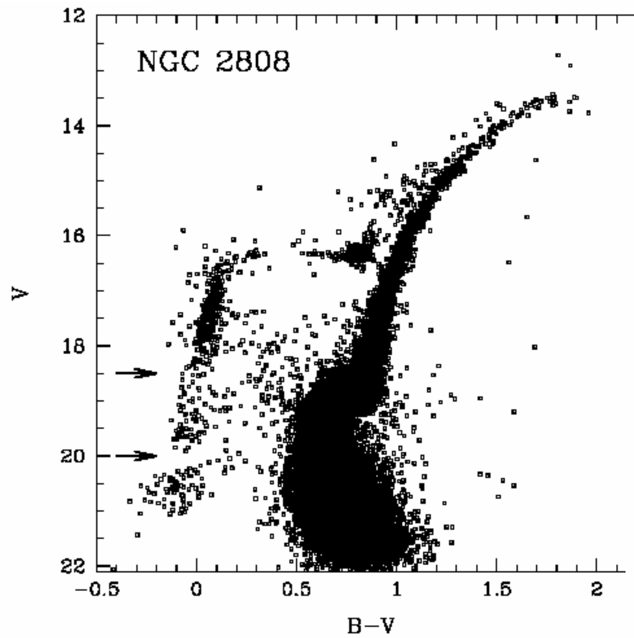
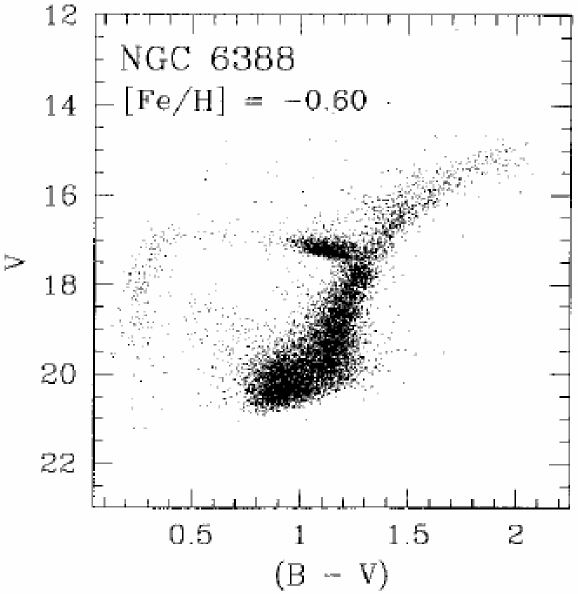
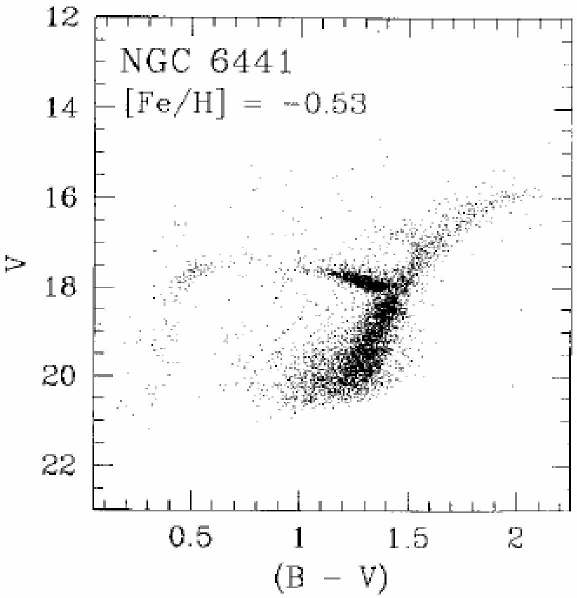
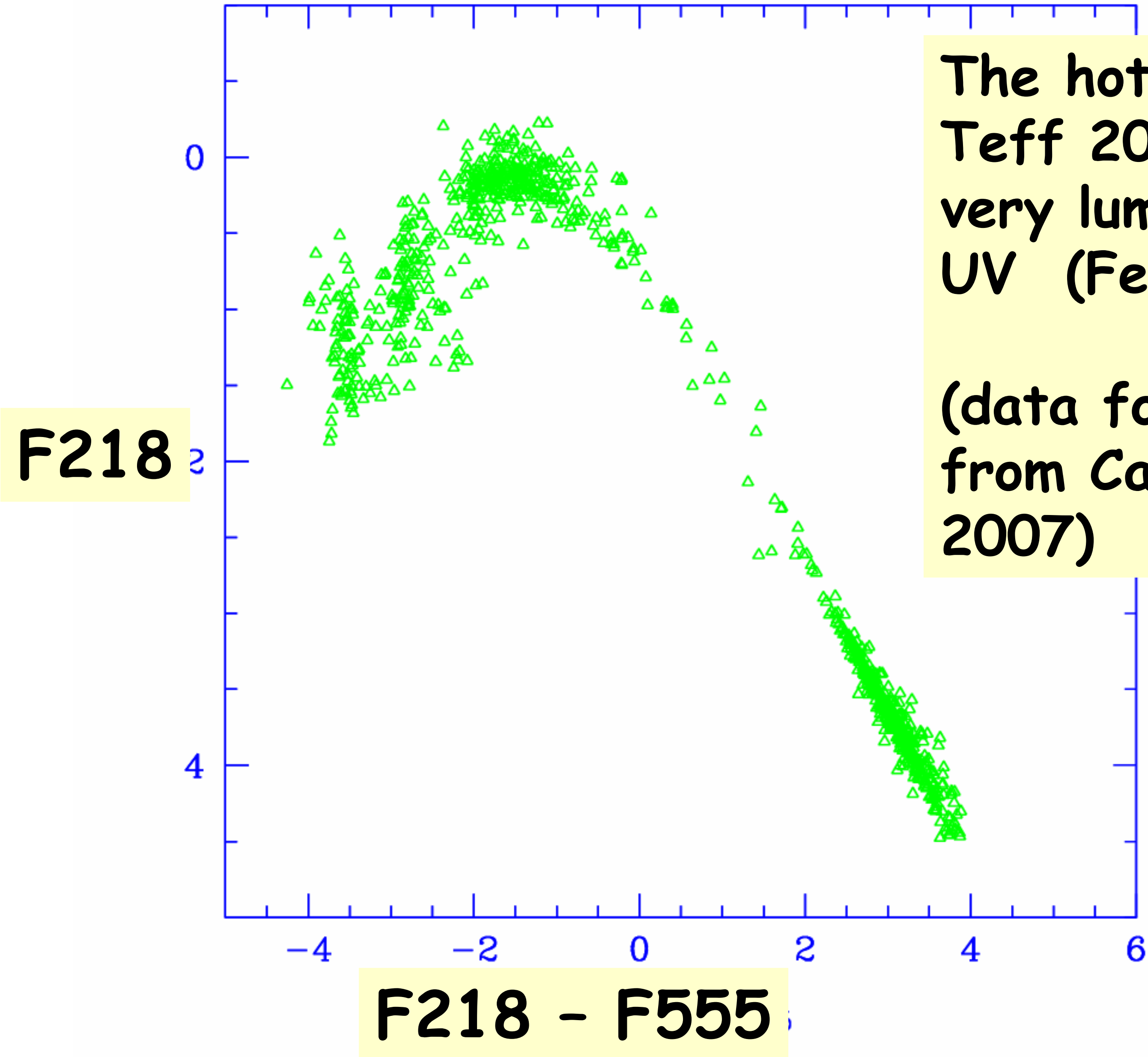

NGC 6752
V
12
14
16
18
20
-.5
0
.5
1
1.5
B-V


47 Tuc
[Fe/H] = −0.71
V
10
12
14
16
18
20
0
0.5
1
1.5
(B − V)


NGC 2808
V
12
14
16
18
20
22
−0.5
0
0.5
1
1.5
2
B−V


NGC 6388
[Fe/H] = −0.60
V
12
14
16
18
20
22
0.5
1
1.5
2
(B − V)


NGC 6441
[Fe/H] = −0.53
V
12
14
16
18
20
22
0.5
1
1.5
2
(B − V)

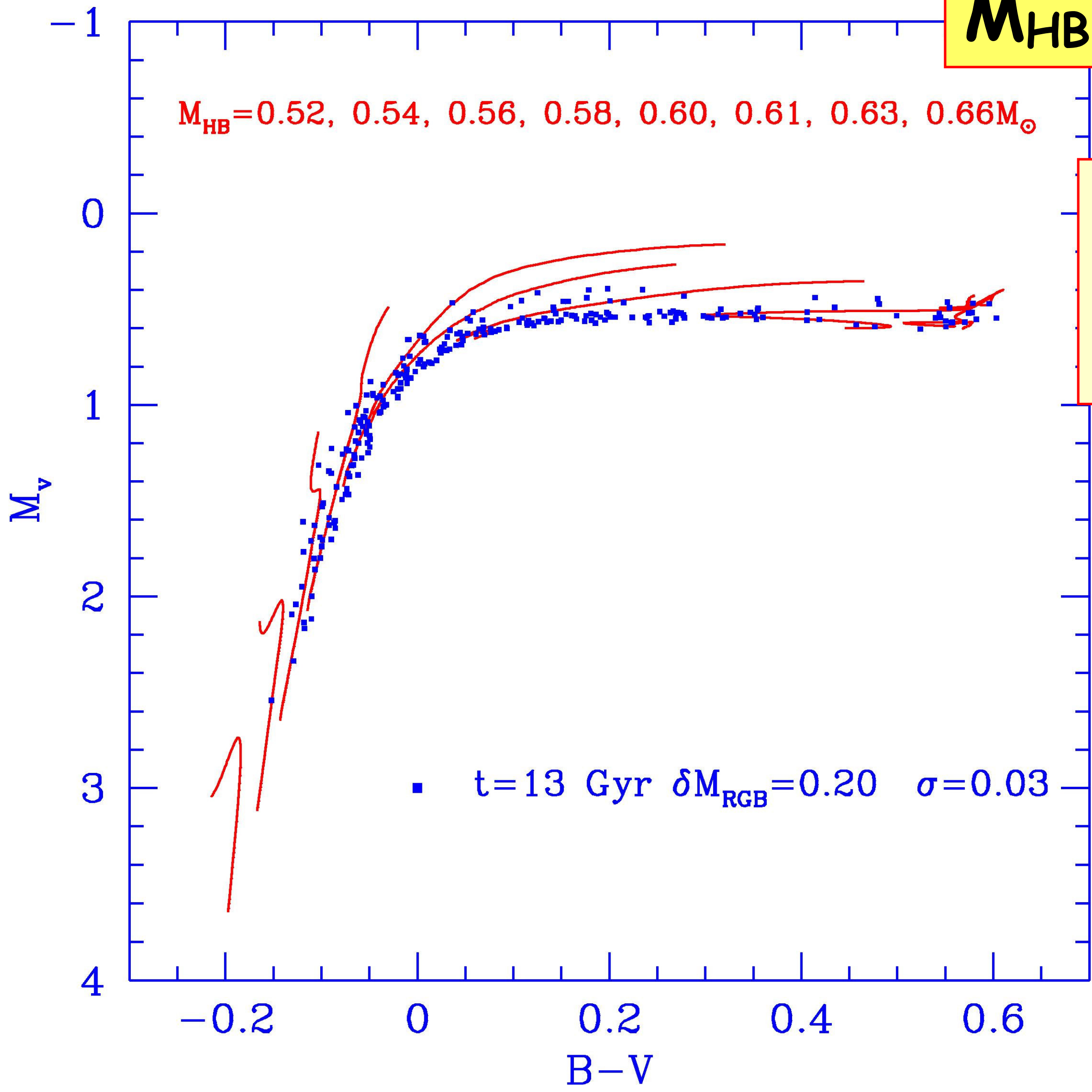


The hot HB stars at Teff 20-30000K are very luminous in the UV (Ferraro's talk)

(data for NGC2808 from Castellani et al. 2007)

The standard approach to HB structure

$M_{HB}=M_{RG}(t,Z,Y) - \delta M$

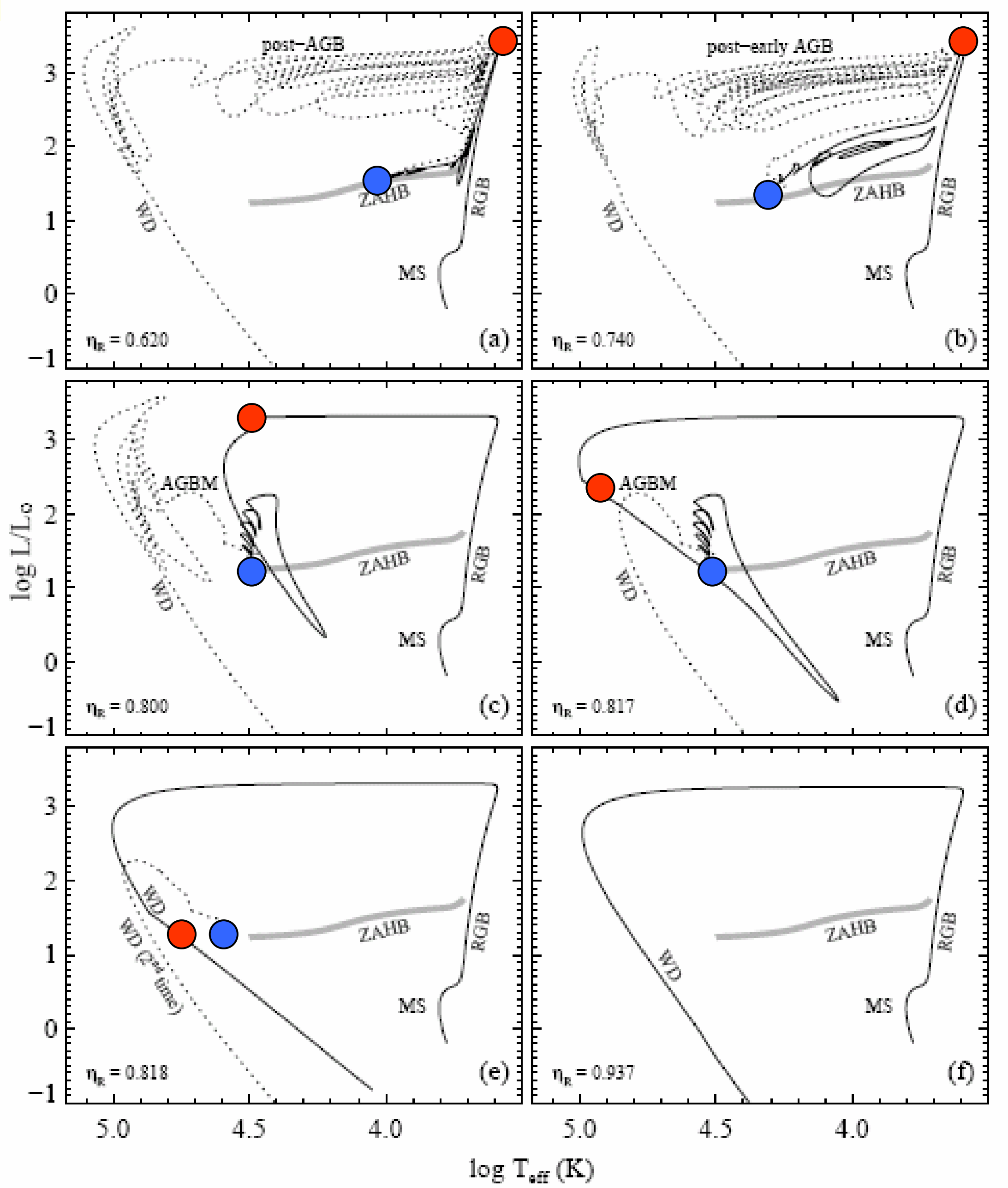


δM has a dispersion σ around a mean value δM_0

σ =0.03Msun and δM_0=0.2Msun gives a well populated red + blue HB like in M3

the bigger is δM, the bluer is the star location in the He-core burning phase

The EHB and “blue hook” stars



Brown et al. 2001

‘Early’ hot flashers leave an HB star with small H envelope: it populates the region 20-30000K.

Flash mixing (Sweigart 1977, Cassisi et al. 1993) causes a discontinuous increase of the HB Teff at the transition between unmixed and mixed models → a gap!

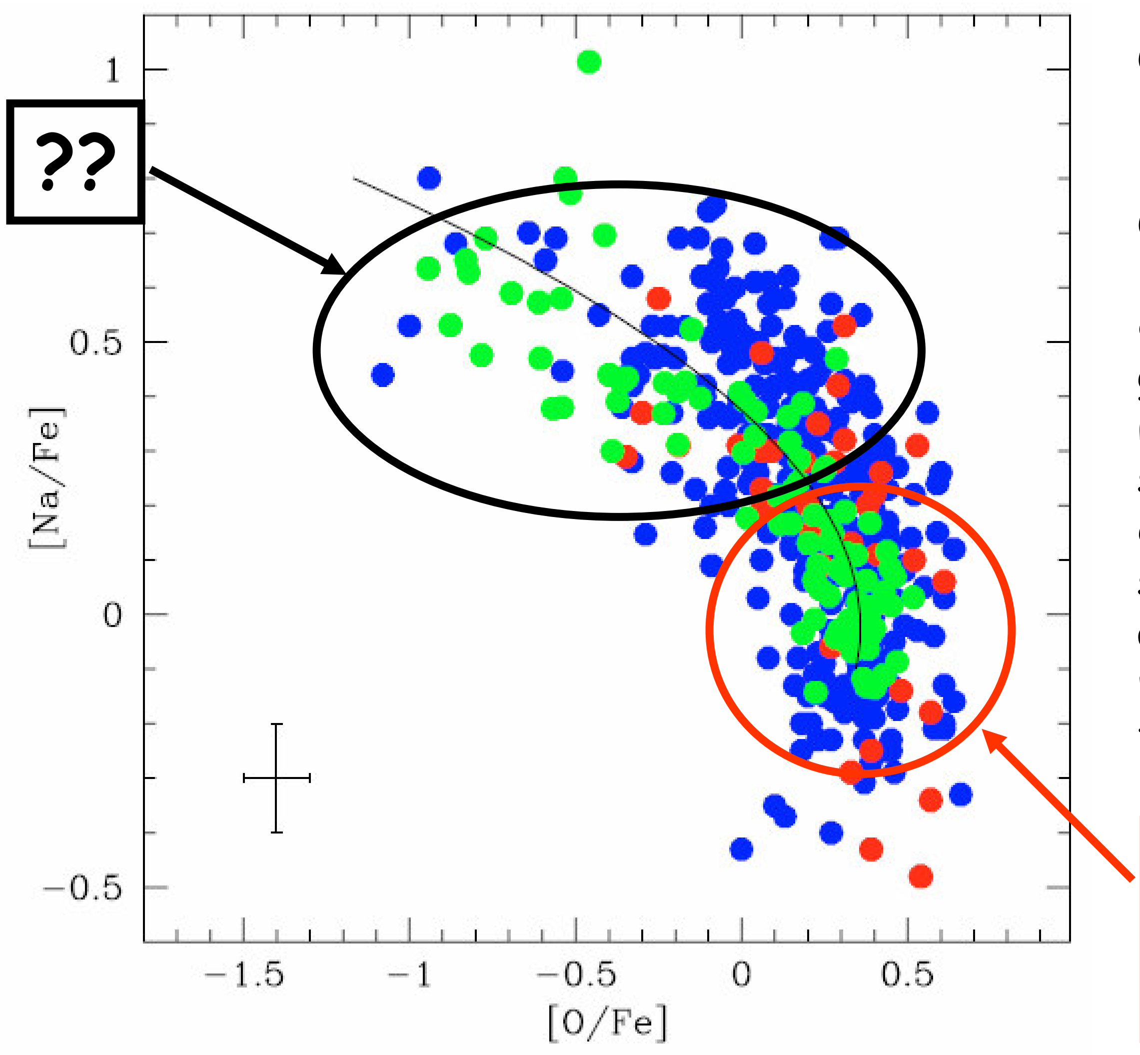
Globular Clusters are not simple stellar populations

1. Spectroscopic observations: Na-O and Mg-Al anticorrelations – (There must be a 'second' star formation event in matter contaminated by hot CNO cycle products) Years: 80s → new obs. ~2001

2. Interpretation of the Horizontal Branch morphology in terms of helium content variations among the GC stars (D'Antona et al. 2002...) →>2001

3. Photometric evidence for main sequence or other splittings in some GCs (Piotto) (→ >2004)

The Na-O anticorrelation



Carretta et al. 2006
A&A 450, 523

Global Na-O anticorrelation (solid black line) superimposed on a collection of stars in about 20 globular clusters. Blue points are RGB stars from literature studies; red points are scarcely evolved stars (turnoff or subgiant stars) from Gratton et al. (2001) and Carretta et al. (2004); green points are RGB stars in NGC 2808 from the present study.

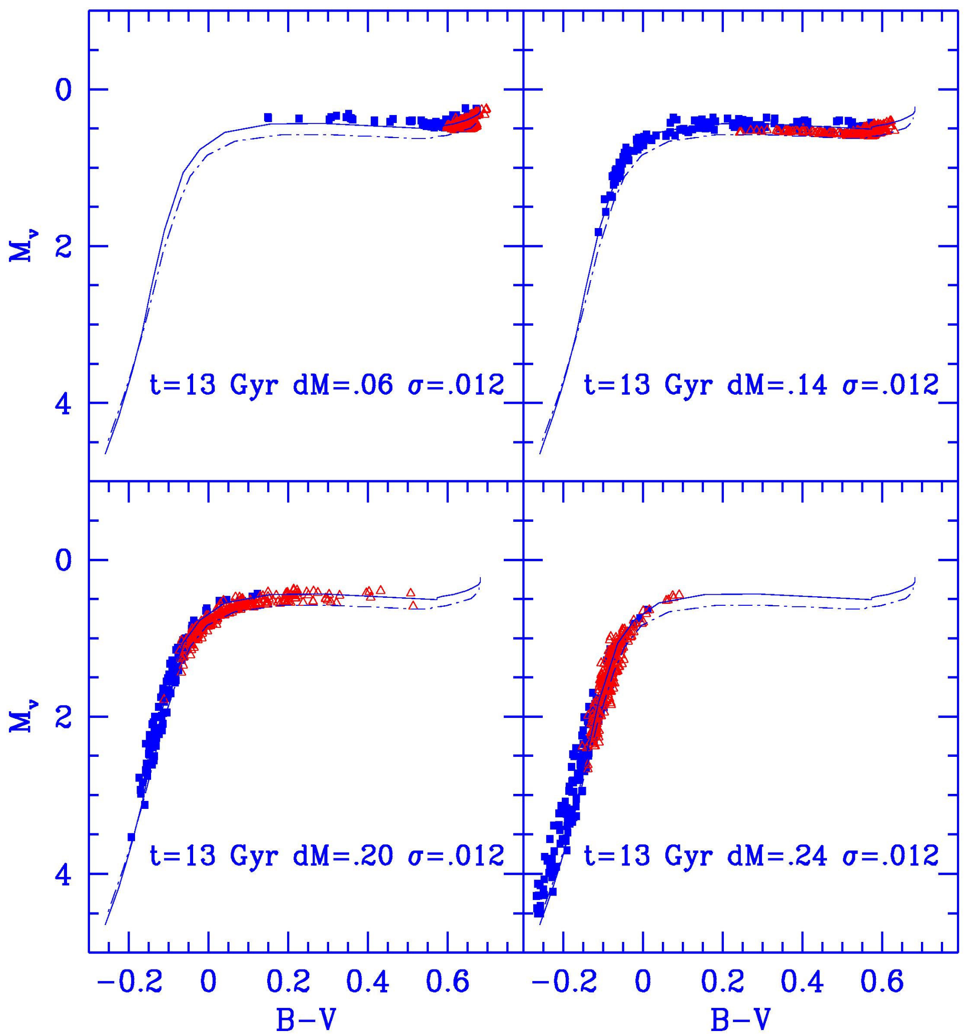
this is the range of abundances in low metallicity field stars

The paradigma of helium variation among GC stars

If there are CNO-NaAl chemical anomalies, there must be some extra-helium! Variations in Y can explain the peculiar morphologies of the horizontal branch in many clusters (gaps, blue tails, extremely hot HB, Periods and period distribution of RR Lyr)

main sequence photometric evidence for helium anomalies confirm the credibility of the proposal. A consistent scenario is emerging in some clear-cut cases

How helium affects the HB morphology



(D'Antona et al. 2002)

For a given isochrone, the evolving (turnoff and RG) mass is smaller for larger Y: $\Delta M \approx -1.3\ (Y-0.24)$

the HB mass is also smaller for larger Y and the star is bluer

adding a population with larger Y extends the HB to the blue

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A parenthesis: the mass loss in RGB does not depend on Y

In spite of different mass and helium, adopting Reimers' mass loss rate along the RGB in fact provides the same amount of mass loss for the evolving stars (at the same age) having Y=0.24 and higher helium up to Y=0.40 (Caloi & D'Antona 2007)

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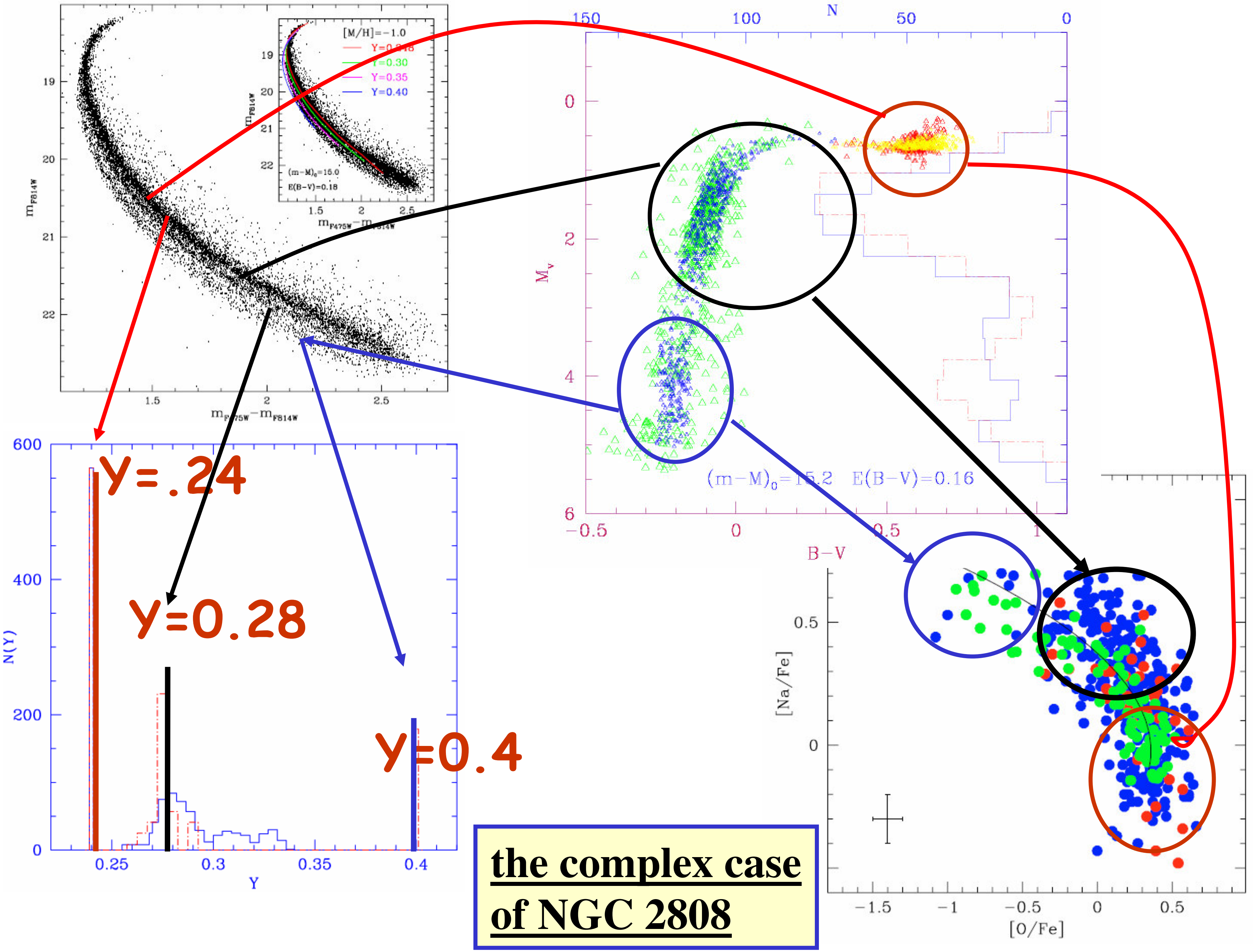
Adding a population with larger helium….

1 … extends the HB to the blue

2 … decreases the mass loss spread necessary to explain the HB morphology!

$$M_{HB} = M_{RGB} - \delta M_0 \pm \sigma$$

“typical” σ~0.02Msun
but now: σ~0.004 – 0.006 Msun is enough
Even, in the case of M3, σ~0.002 is necessary to understand the extremely peaked RRLyr period distribution (CD2008)



the complex case of NGC 2808

Also in other GCs, a non negligible fraction of stars is recognized to have $0.37 \leq Y \leq 0.42$

ω Cen and NGC 2808 (MS splittings!), NGC 6441 and NGC 6388 (HB peculiarity) belong to this class.
What % of stars must have very high Y?

ω Cen:	25%	(Bedin et al. 2004)
NGC 2808:	15%	(Piotto et al. 2007, D'Antona et al. 2005)
NGC 6441:	15%	(Caloi & D'Antona 2007)
NGC 6388:	20%	(D'Antona & Caloi 2008)

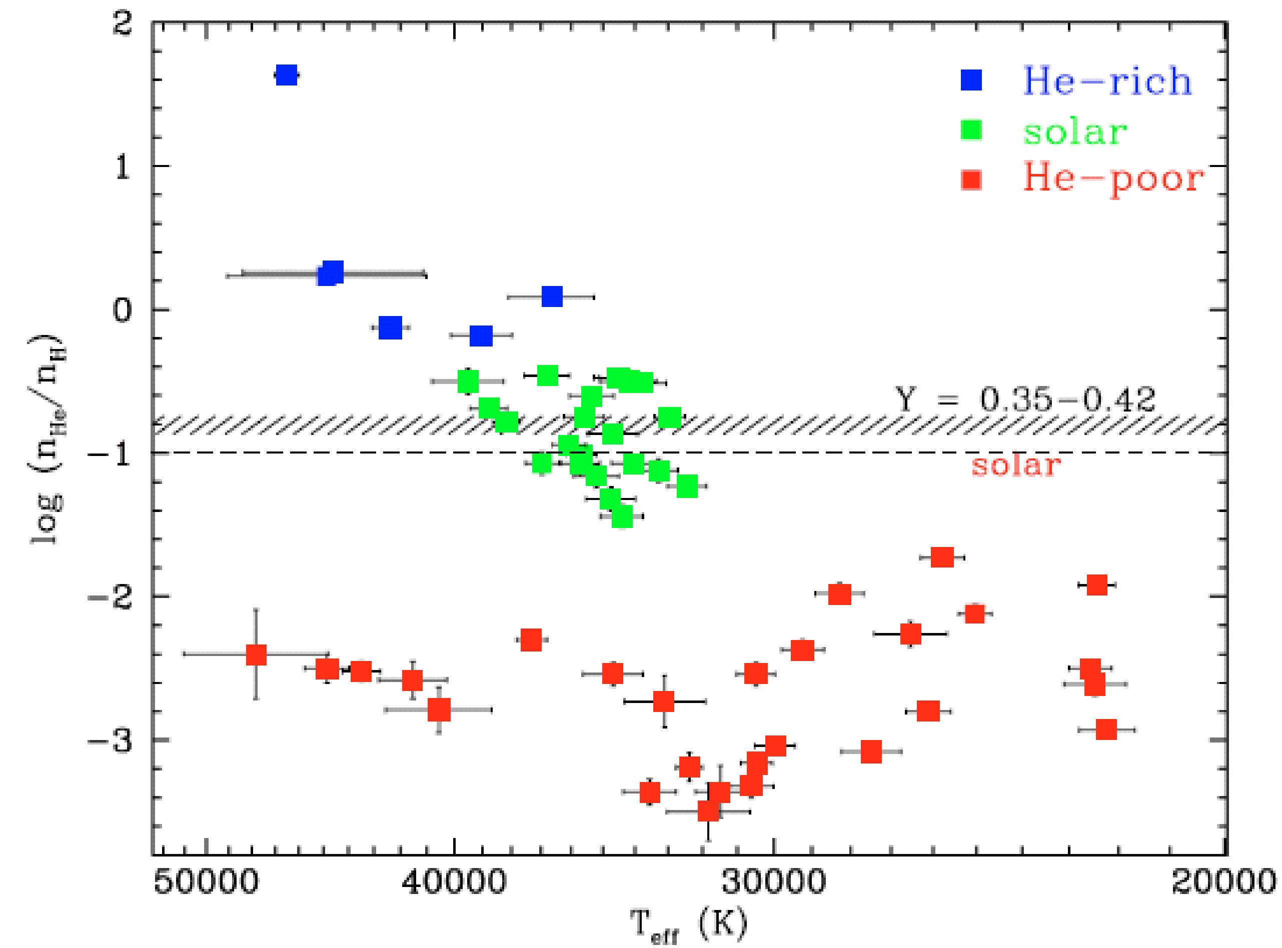
The “standard” approach

In the standard approach, the EHB and blue hook stars are born if some RGs lose so much mass that they will not be massive enough to suffer the helium core flash at the RG tip.

the extra mass loss was traditionally attributed to an effect of the environment (e.g. central high stellar densities) on the mass lost from the RG.

New recent results

"**The hottest HB stars in ω Centauri. Late hot flasher vs. helium enrichment**" (S. Moehler et al.2007)



A fraction of ~15% of the blue hook stars is much more He-rich than predicted from the He-rich MS (Y~0.4), and have high C!

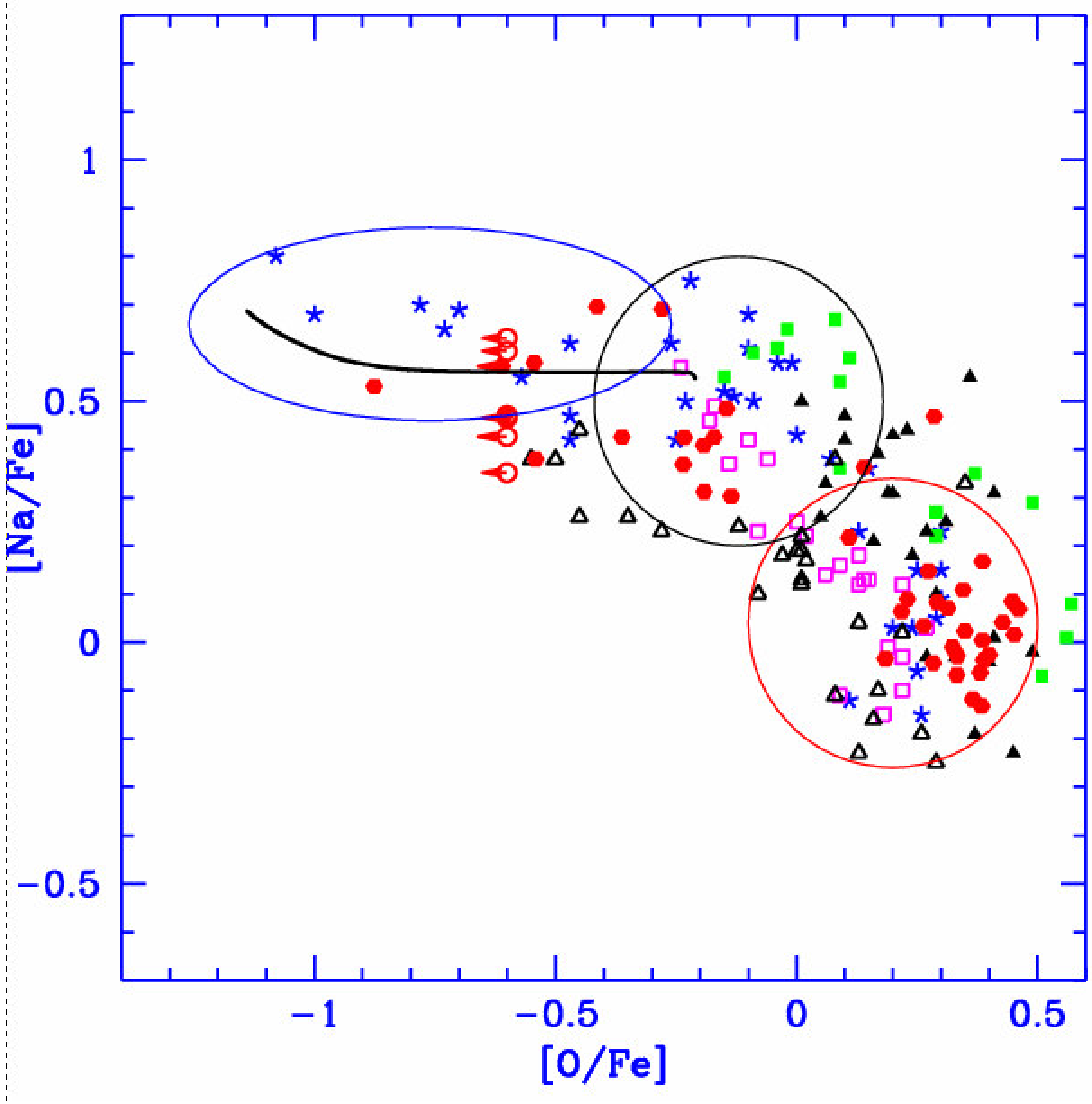
But WHY "late hot flasher vs. helium enrichment"?

If there is a fraction of very high helium stars in MS, the RG corresponding mass is so low (depending of the composition M_{RG}~0.6Msun for Y=0.4) that **the stars which miss the He-flash on the RGB are "necessarily" the extreme He rich stars**, (if the mass loss rate is substantially independent of Y, as it is according to computations)

Is flash mixing the only possible reason for High helium ?

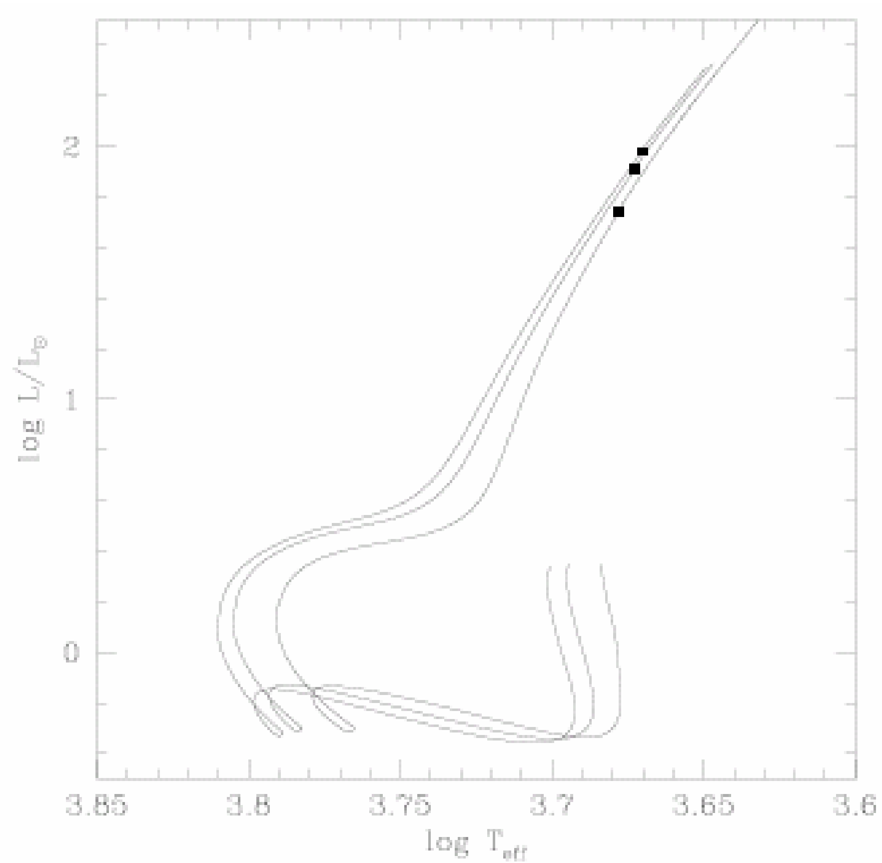
Deep mixing in Red Giants

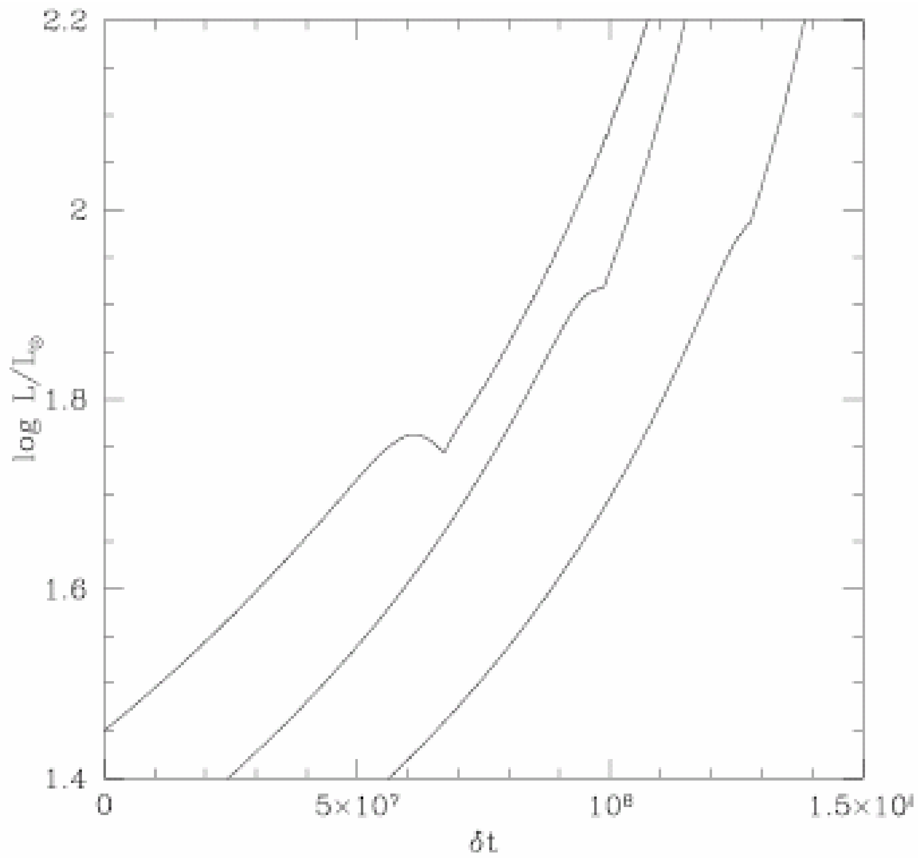
Models for self-enrichment (both in AGB and in very massive fast rotating stars pollutors) do not predict δ[O/Fe]<~-0.8. In fact, the stars showing even lower O are only giants (Carretta et al. 2006)



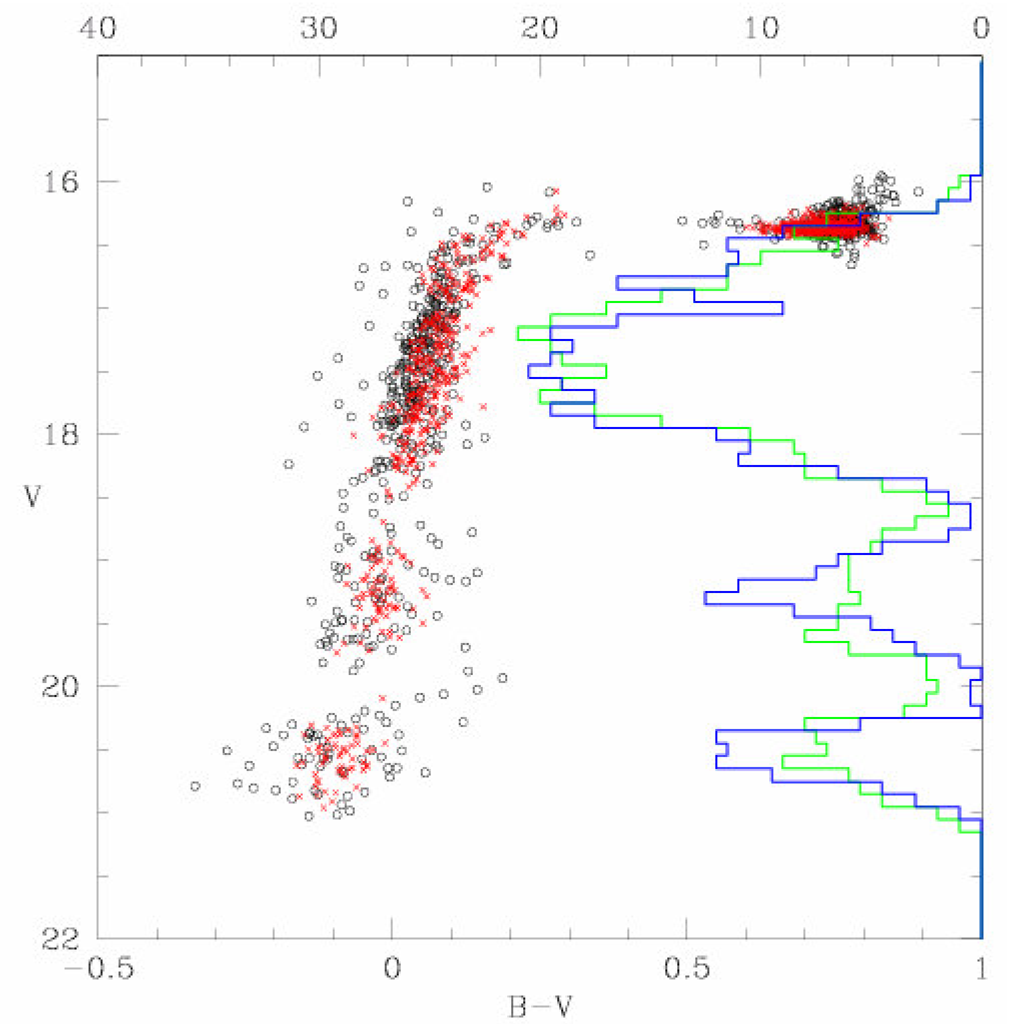
The lowest oxygen abundances might be due to non standard mixing in very He rich giants, and deep mixing also increases the helium abundance. So from Y~0.4 it can raise up to Y~0.5, or even much larger, depending on the modalities of mixing

D'Antona & Ventura 2007, MNRAS





the discontinuity left by the maximum deepening of convection in RGB is very reduced in Y~0.35 - 0.40 models (D'Antona & Ventura 2007) and rotationally induced mixing can be efficient also below the "red giant bump".



simulation including stars with high MS helium (Y=0.37) but with very high envelope helium (Y=0.6-0.8) allow to reproduce the gap in the distribution of the EBT2+EBT3 stars, both descendants of the Y~0.4 MS

Further work

* better modeling of deep mixing in Red Giants, using rotating models

* explain the difference between the HB distribution in

M13 → NGC 2808 → ω Cen

M13	NGC 2808	ω Cen
no blue hook, but extremely low O	blue hook present, and N(EHB + blue hook) is ~ N(blue MS)	blue hook, possibly many stars avoided the He-flash and are He-WD