A signature of multiple stellar populations in bright metal-rich M31 globular clusters?

Fusi Pecci, Bellazzini, Bragaglia, Buzzoni, Carretta, Federici, Galleti, Perina, Rich

INAF - OSSERVATORIO ASTRONOMICO
BOLOGNA

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- What's the news about/from MW GCs….. MW GCs ≠ Simple Stellar Populations
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- The FUV and NUV GALEX data for MW+M31 GCs

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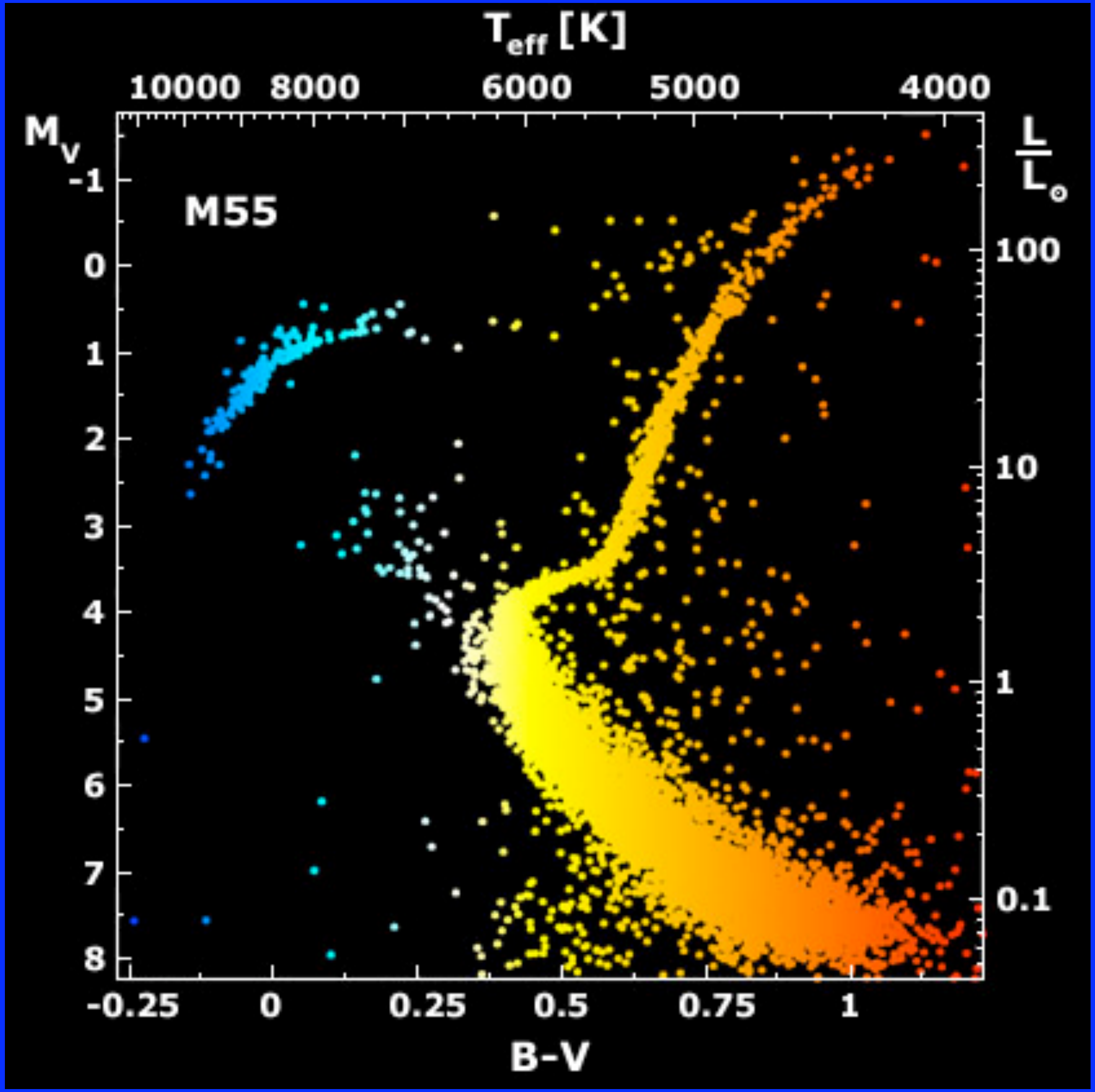
- Any impact on cosmology? Should we worry about? - Conclusions 3

- ciao ciao !!

GCs useful tools to study f.i.:

- Stellar evolution
- Stellar dynamics
- Distance indicators
- Peculiar objects (variables, binaries, blue stragglers, millesecond pulsars, etc.)
- Templates of stellar populations
- Parent galaxy formation, evolution, masses, etc.
- Constraints on cosmic age, helium abundance, etc.

- etc. etc.



T_{eff} [K]
10000
8000
6000
5000
4000
M_V
-1
0
1
2
3
4
5
6
7
8
M55
L/L☉
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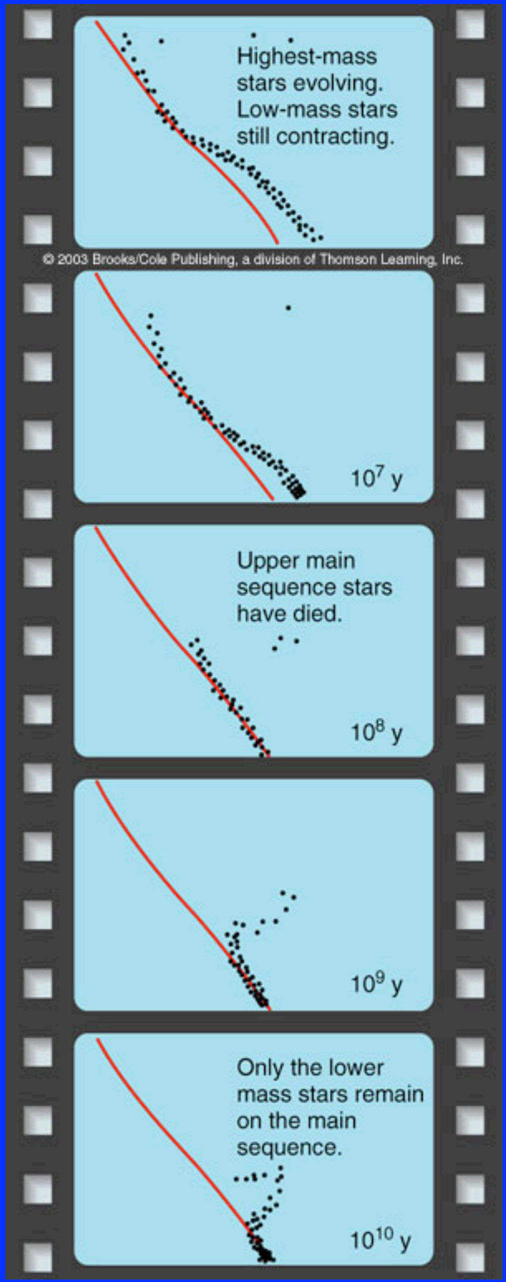
0.1
-0.25
0
0.25
0.5
0.75
1
B-V



Highest-mass stars evolving. Low-mass stars still contracting.
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10^7 y
Upper main sequence stars have died.
10^8 y
10^9 y
Only the lower mass stars remain on the main sequence.
10^{10} y

Questions?

- What's the news about/from GCs in the Milky Way?

GCs are not as "Simple Stellar Populations" (SSP) as thought so far !!

- Is this evident also in extra-galactic GCs?

Simple Stellar Population (SSP)

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

SSP : described by Age, Composition (Y, Z), Initial Mass Function

Best examples: Star Clusters (massive)
Renzini & Buzzoni 1986

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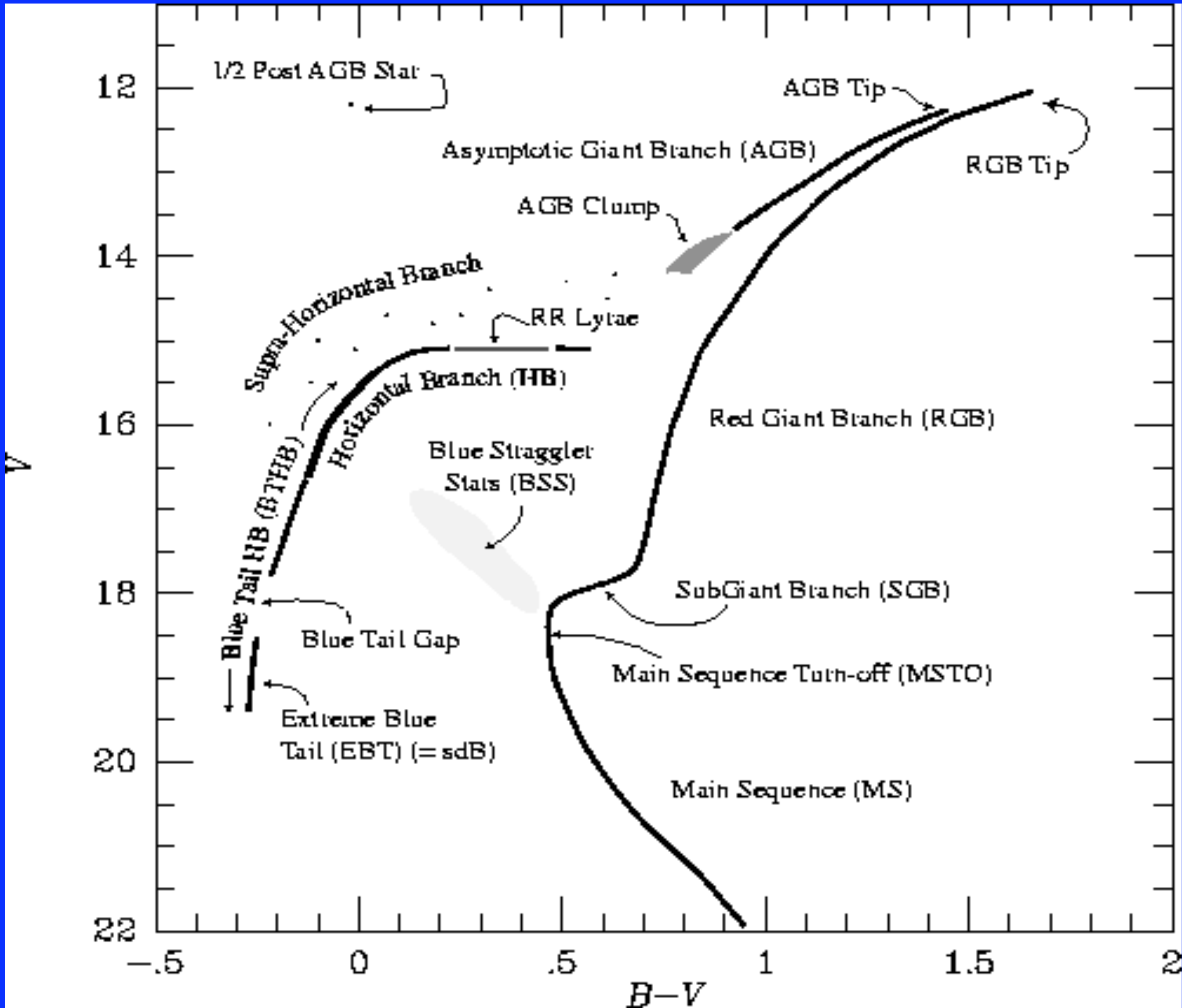
1/2 Post AGB Star
AGB Tip
Asymptotic Giant Branch (AGB)
RGB Tip
AGB Clump
Supra-Horizontal Branch
RR Lyrae
Horizontal Branch (HB)
Red Giant Branch (RGB)
Blue Straggler
Stars (BSS)
Blue Tail HB (BTHB)
SubGiant Branch (SGB)
Blue Tail Gap
Main Sequence Turn-off (MSTO)
Extreme Blue
Tail (EBT) (= sdB)
Main Sequence (MS)
V
12
14
16
18
20
22
−.5
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.5
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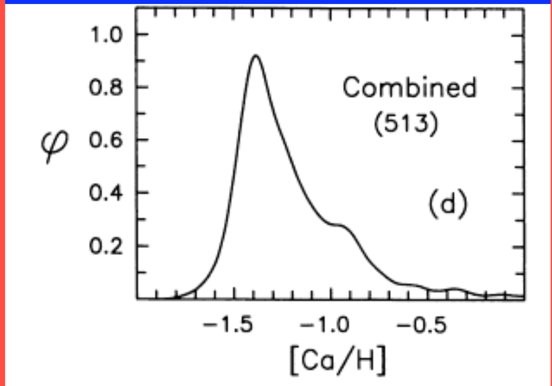
1.5
2
B−V

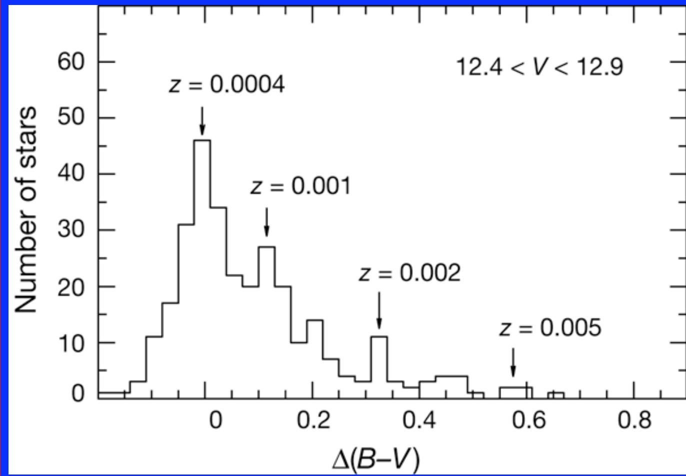
Not all GCs were created simple

...from the “classical” **ω Cen** ...

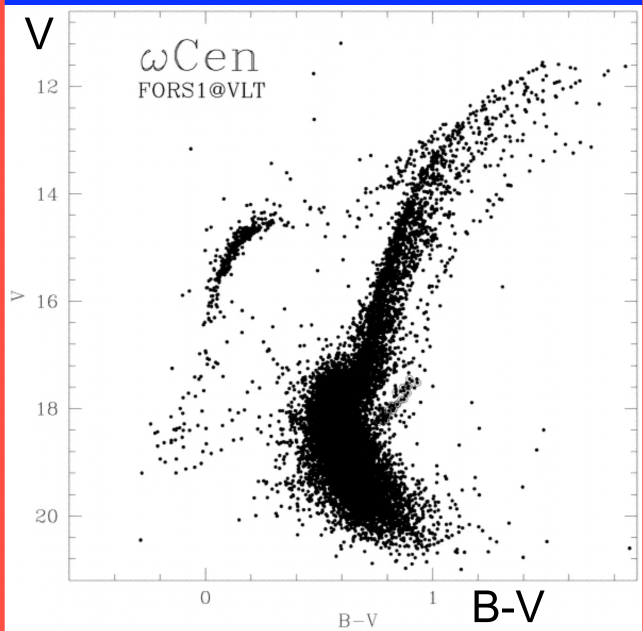
Norris et al. 1996



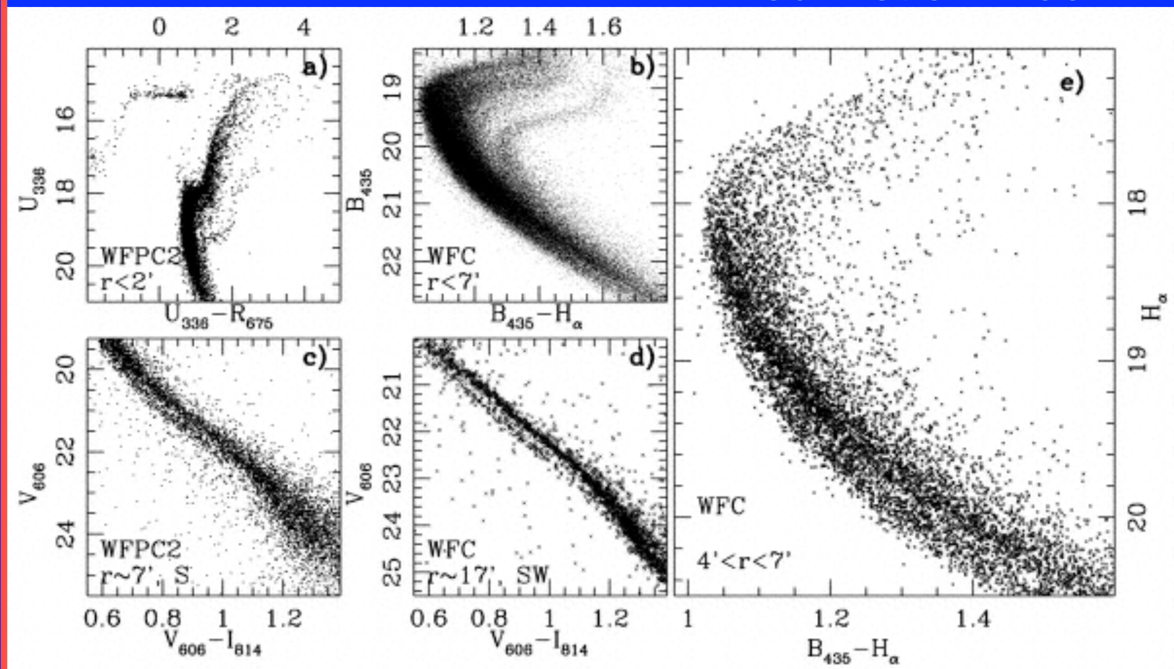
Lee et al. 1999



Ferraro et al. 2004

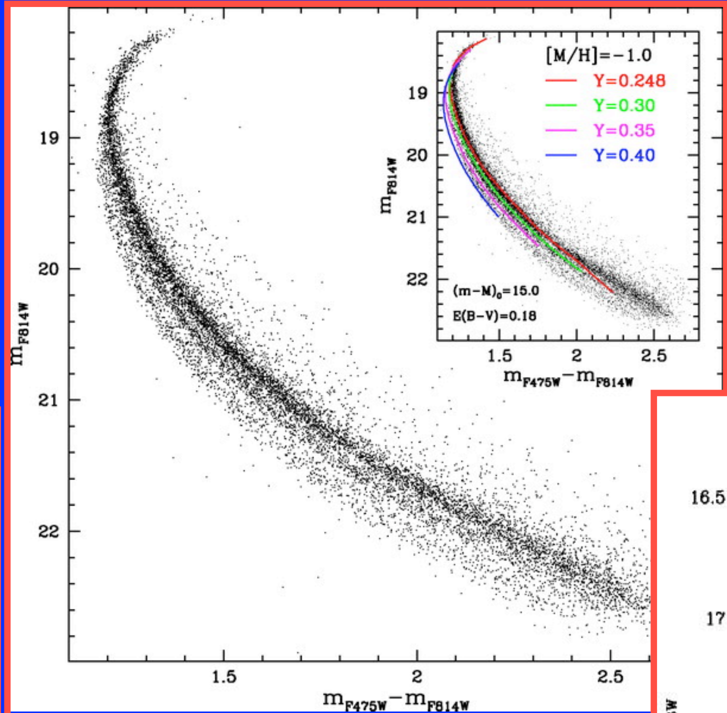


Bedin et al. 2004

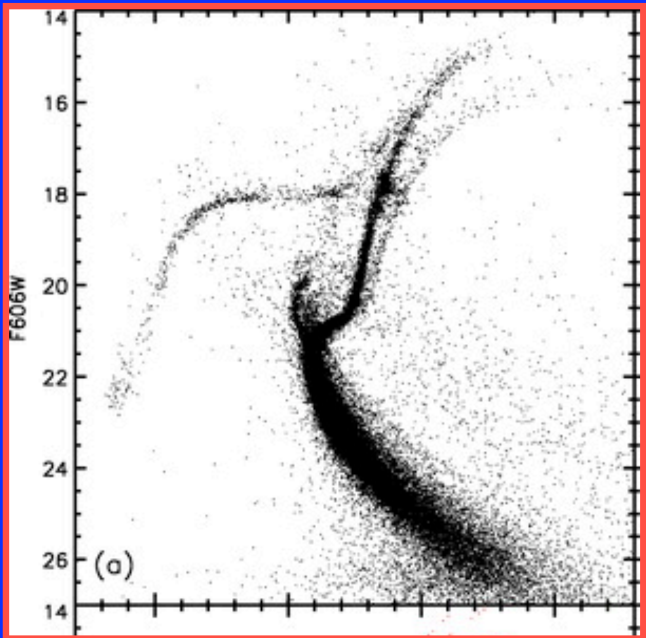


Not all GCs were created simple

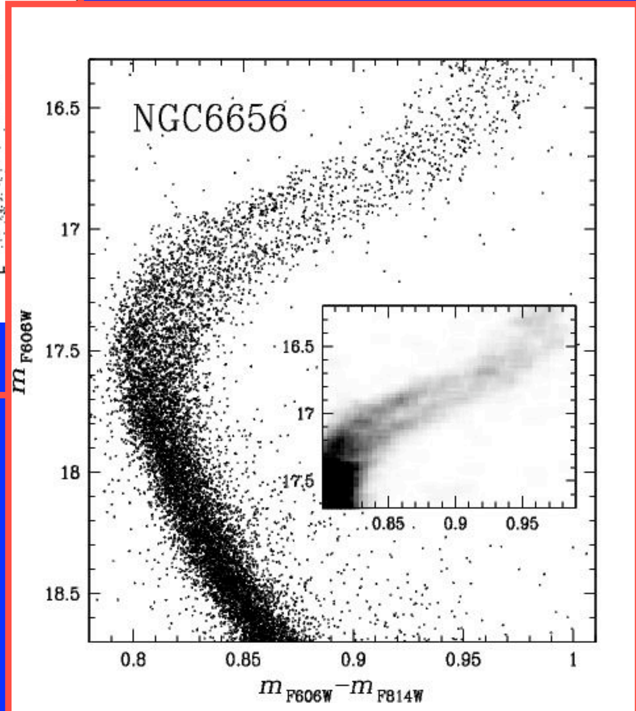
...to M54, NGC 2808, M22, etc ...



NGC2808: Piotto et al. 2005



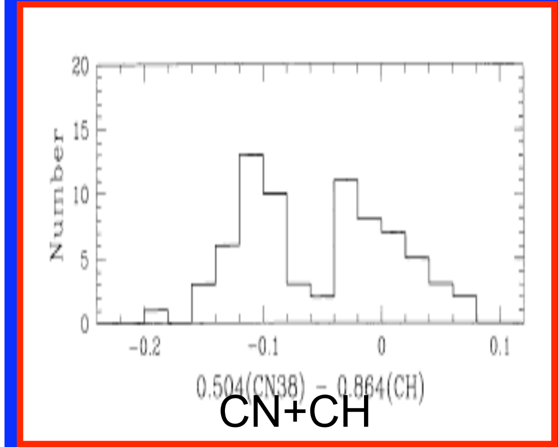
M54: Siegel et al. 2007

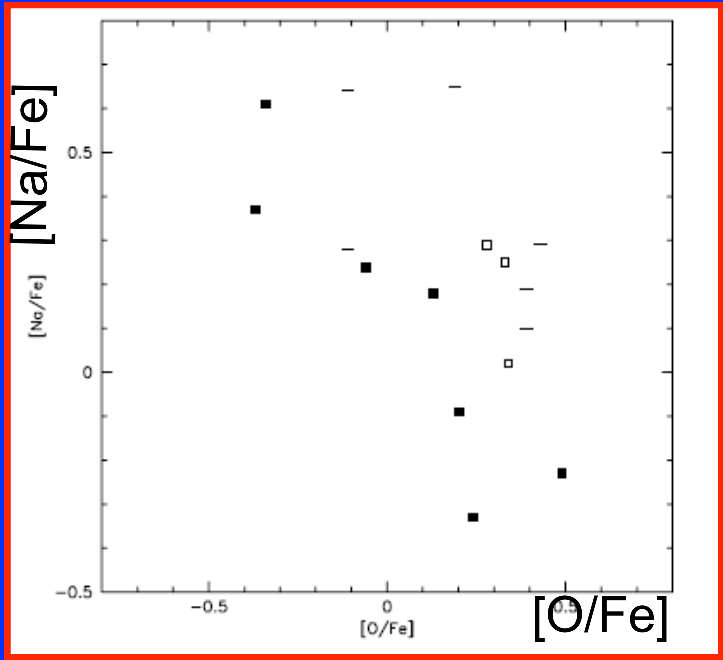


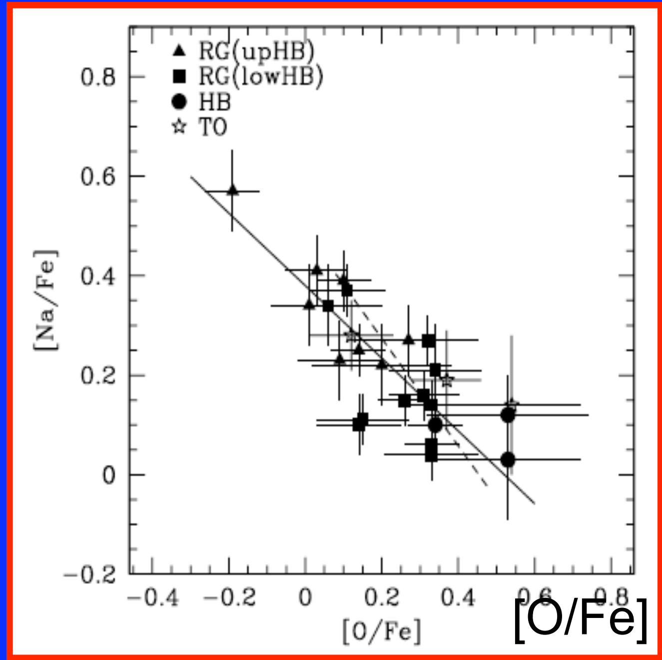
M22: courtesy A.Milone

Not all stars were created equal

(…with the same initial chemical composition…)







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**

Conclusions from the MW GCs

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

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Let’s go to the use of GCs as templates of stellar populations

and, in particular,to the

importance and impact

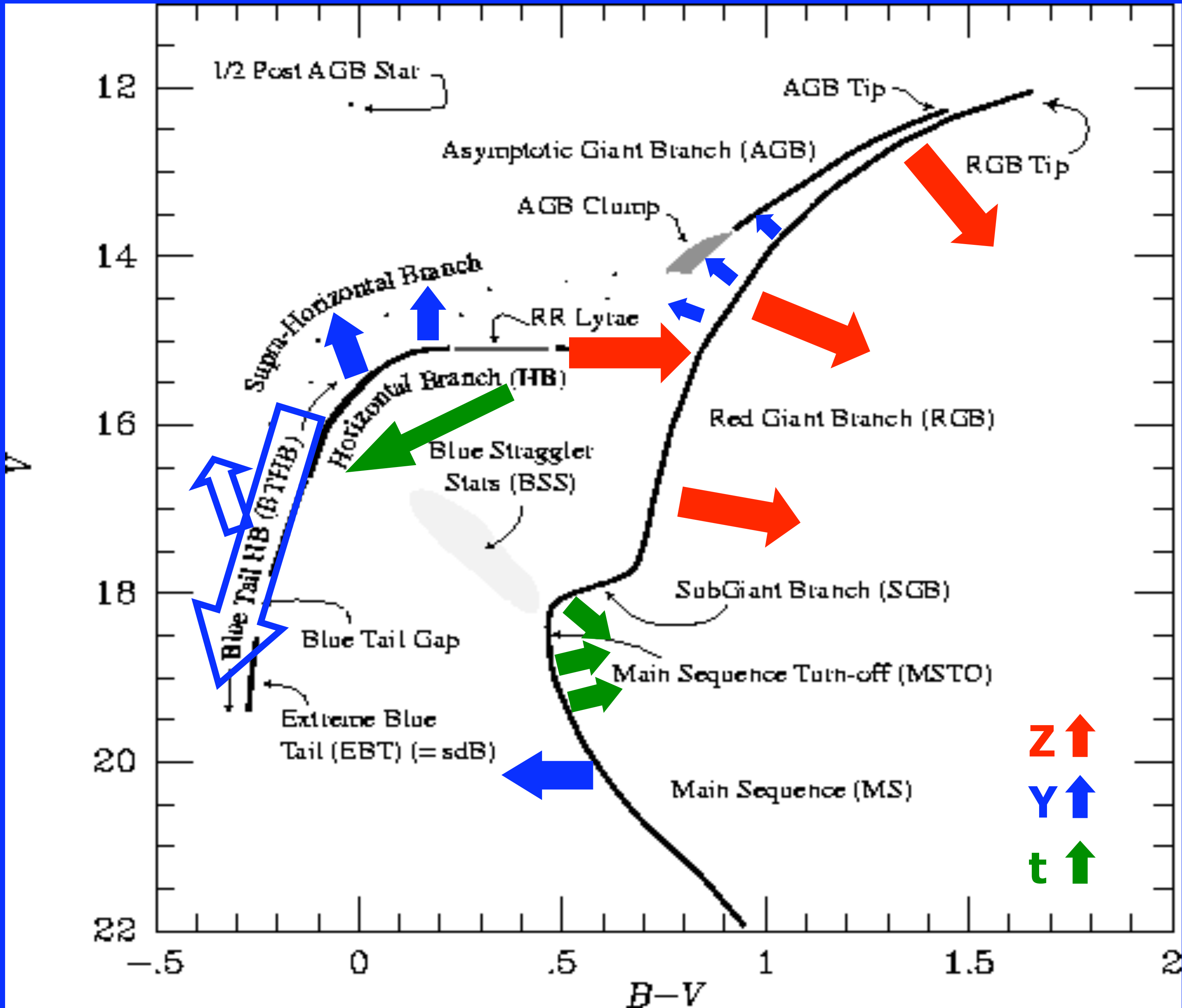
of the

Population and Morphology

of the Horizontal Branch

on history/abundance/age - estimates

of GCs and complex stellar populations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Main Sequence (MS)
Z
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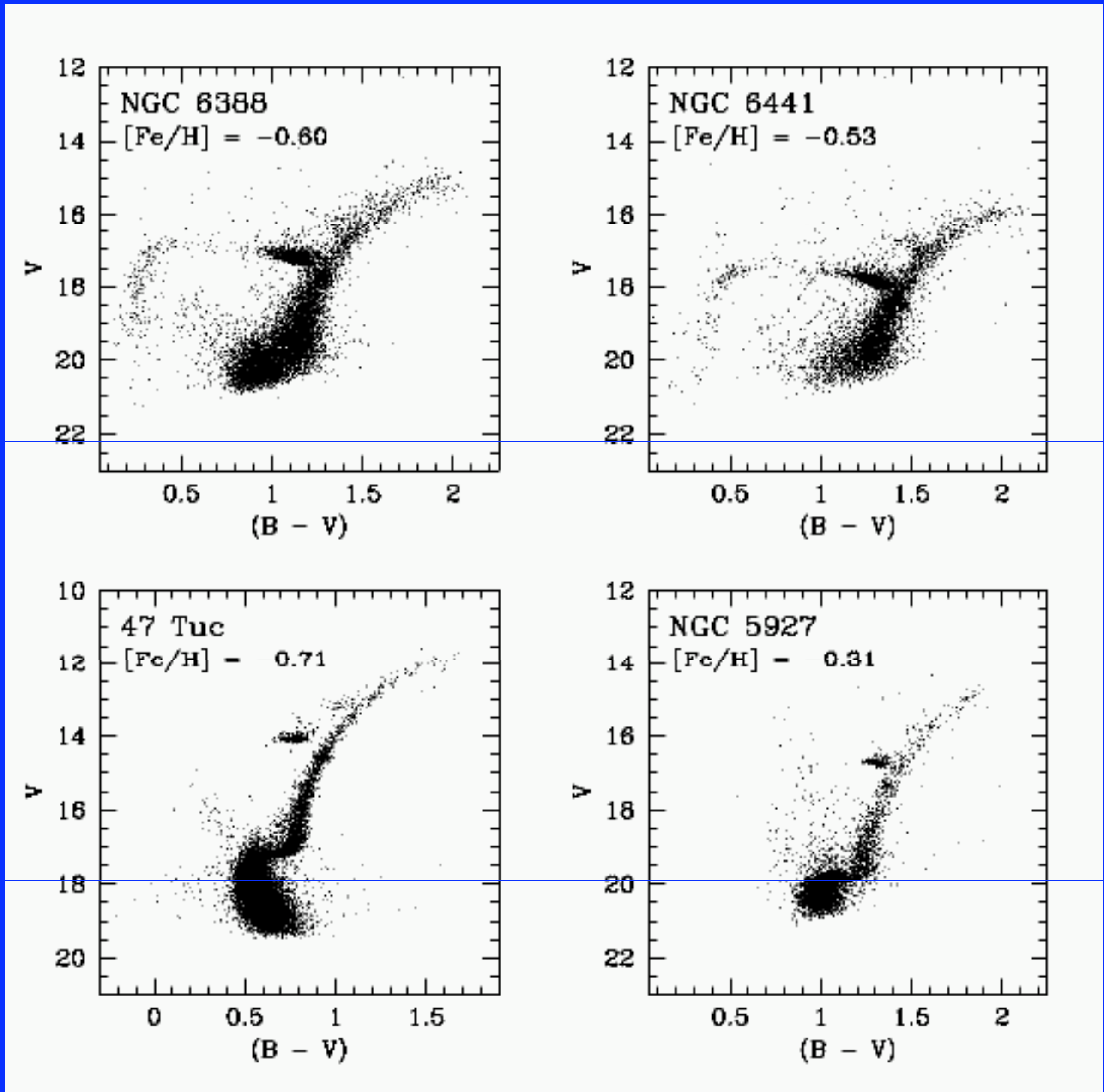
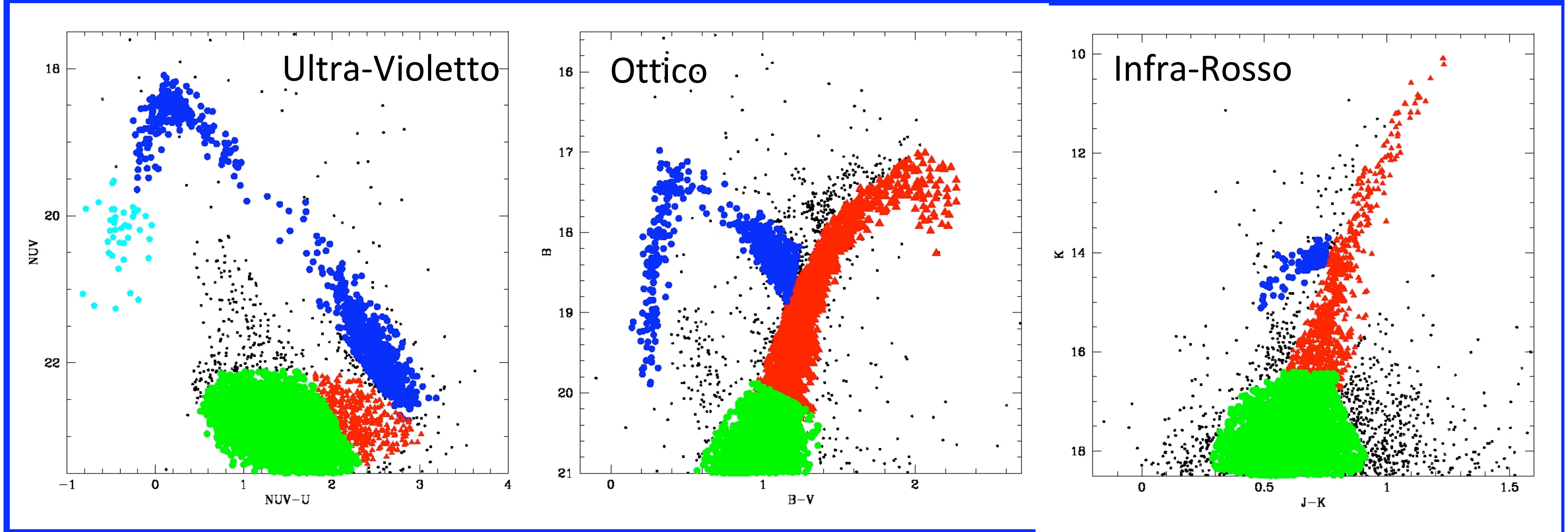
STRIKING examples in MW GCs



Rich et al. 1997

NGC 6388

SEQUENZA PRINCIPALE
RAMO DELLE GIGANTI
BRACCIO ORIZZONTALE



Ideal to study HOT sequences:
- HB stars
- BSS stars

Ideal to study the TO region

Ideal to study COOL sequences:
- AGB stars
- RGB stars

Let’s see in M31 GCs, we use:

- The published GALEX sample (Rey et al. 2005, 2007) for MW + M31 GCs UV-data

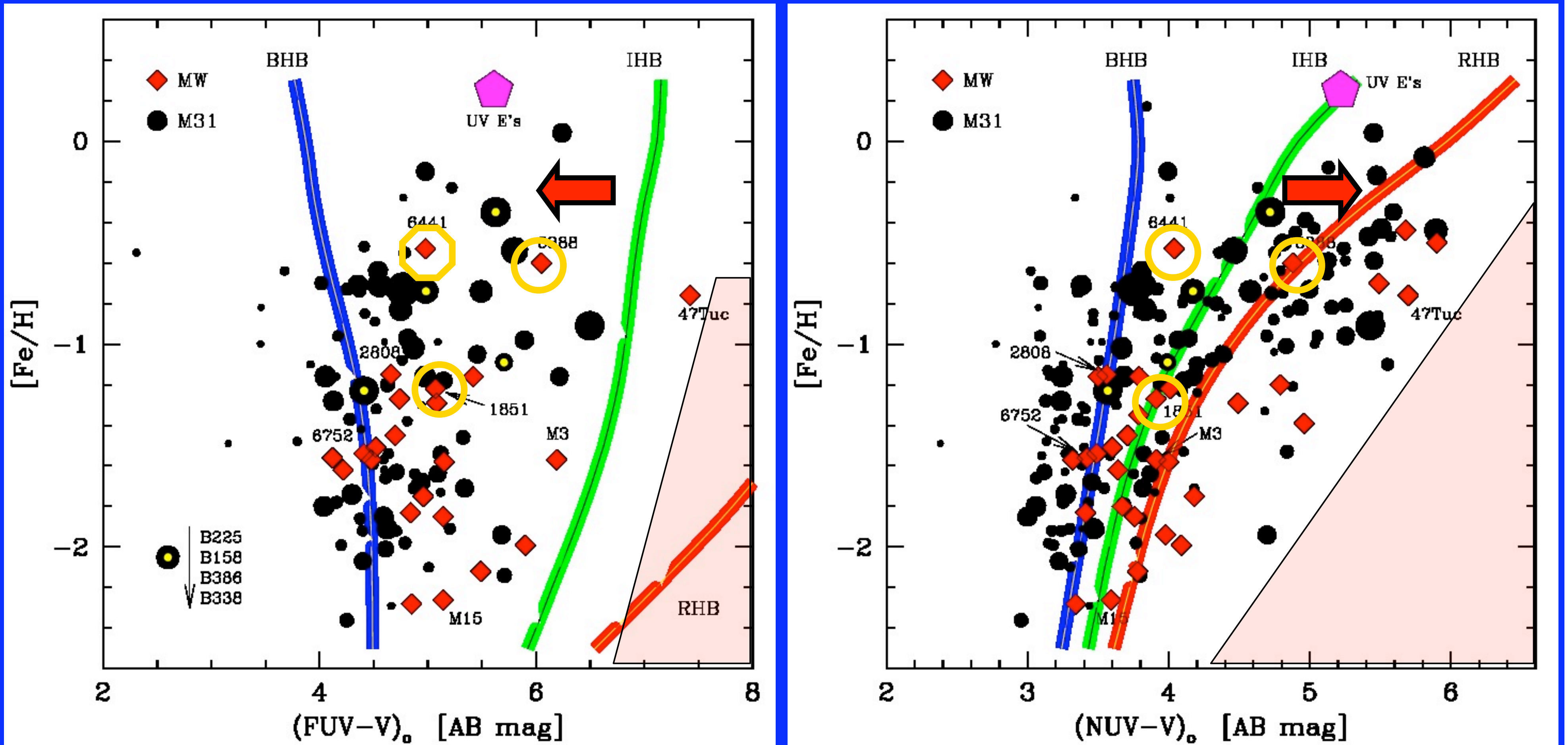
+

- The Revised Bologna Catalog (Galleti et al. 2005, 2009) for the photometric + spectroscopic data for M31 GCs

Metallicity vs. UV-GALEX

dot-size ↑ if Mv ↑

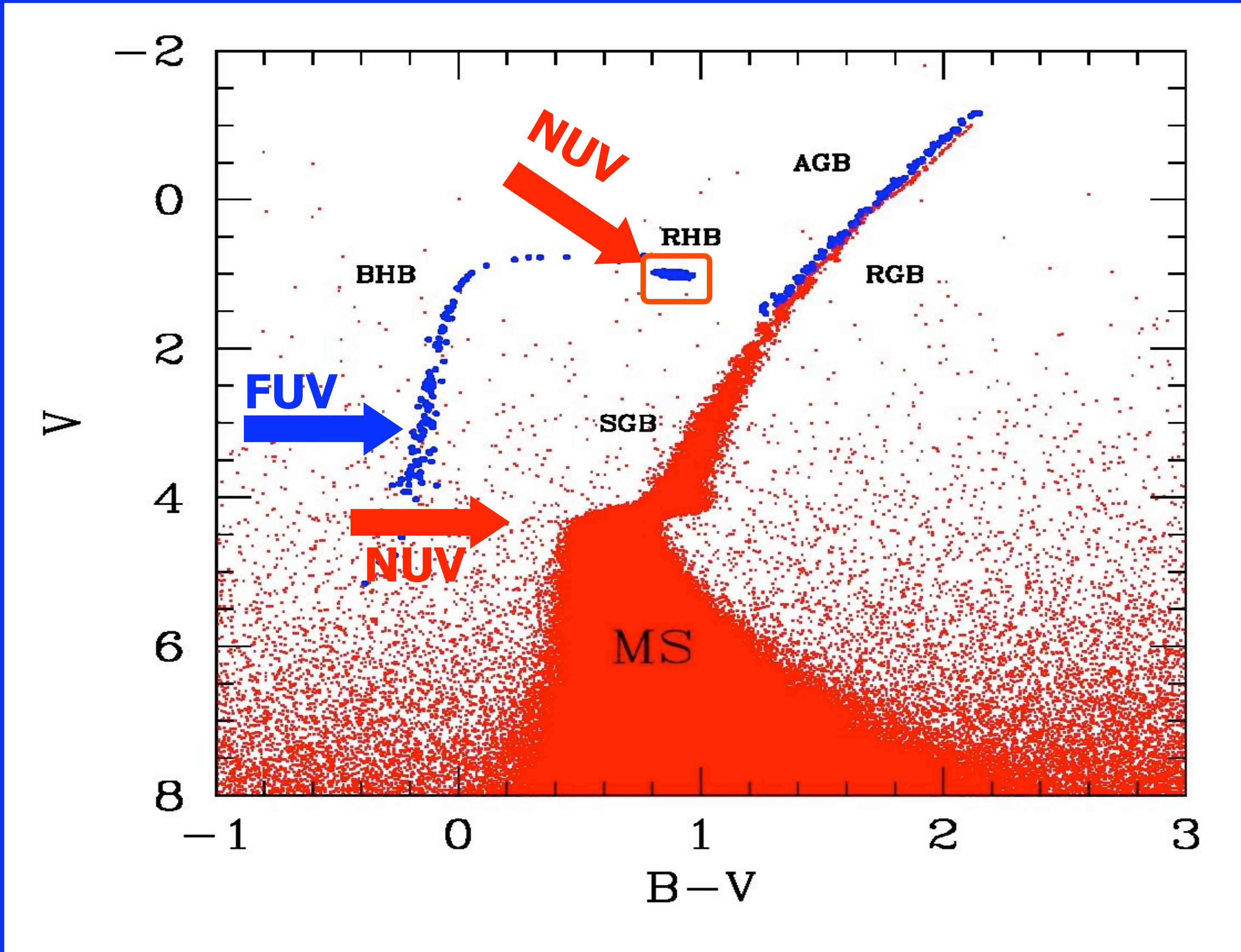
BHB → UV upturn?



FUV (1500Å)

NUV (2300Å)

Major contributors to …



Conclusion No. 1

- As shown for NGC 6441 & 6388, there is a quite wide group of metal-rich GCs in M31 which share the UV-excess + BHB anomaly
- Most of these objects are among the brightest metal-rich GCs in M31, brighter (i.e. more massive) than ω Cen in the MW

Three questions

- Can the above hints be directly confirmed by available observations?
- If not (yet) is there any further observational data or feature which could help adding specific info on these GCs?
- If so, is it conceivable to explore the possible intrinsic origin of these evidence within a plausible evolutionary scenario for these clusters?

Speculation No. 1

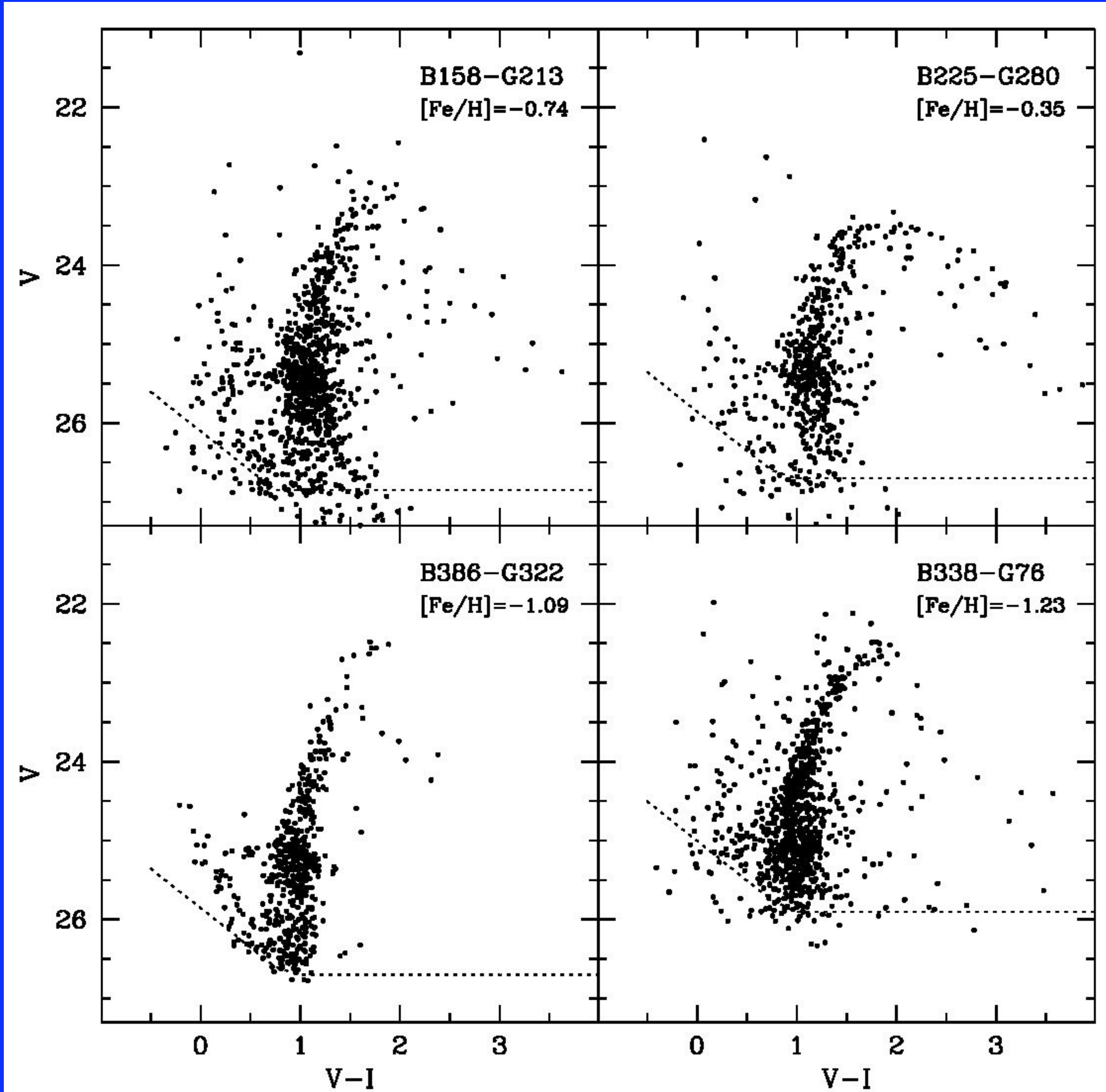
• If the peculiarities and the overall scenario described for the GCs in the MW is confirmed…

•It is obvious that the **best tool** to detect such "peculiarities" elsewhere is to secure photometry and spectra of the **individual stars** in as many clusters as possible

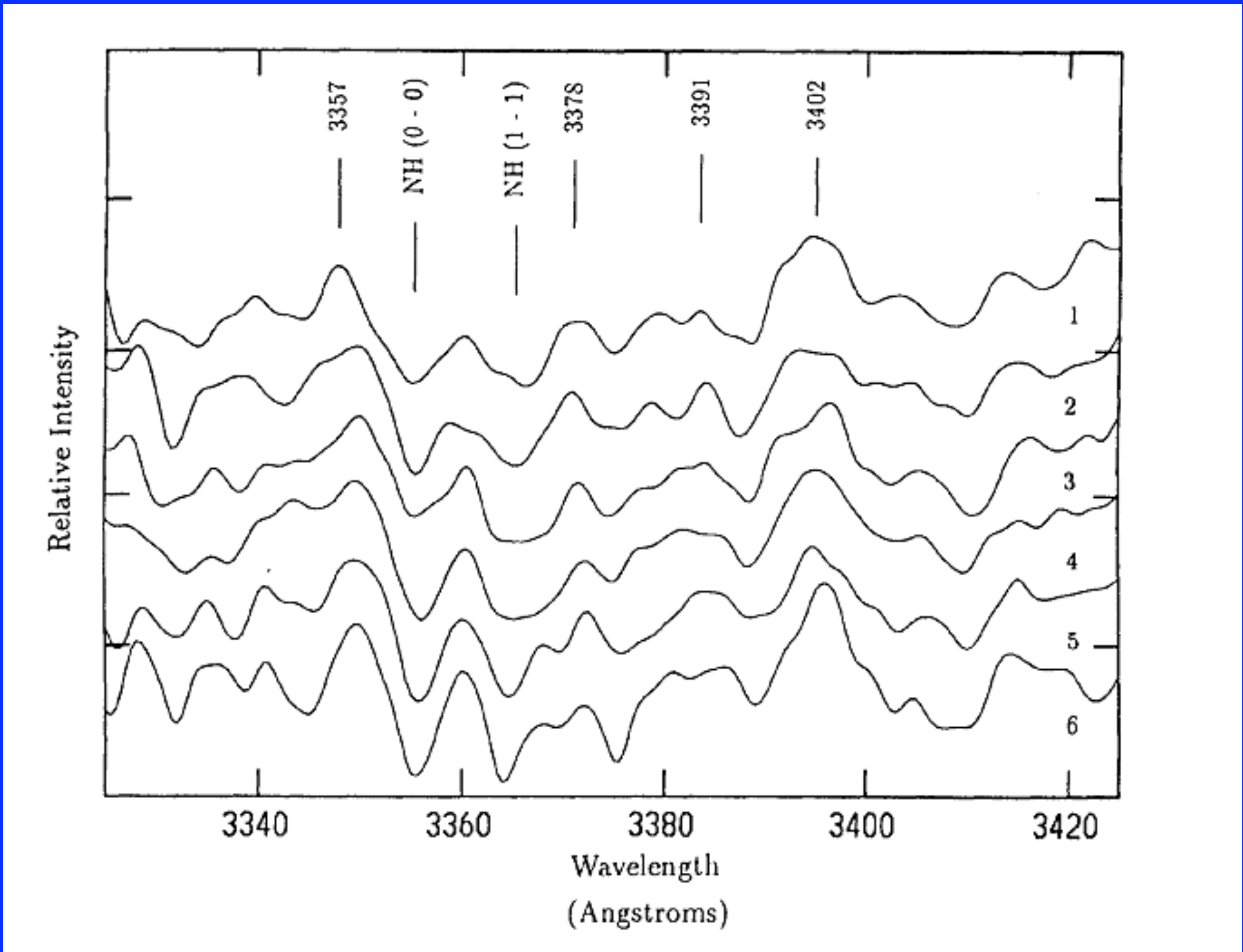
•However, it is also conceivable that, (a) if the star-to-star variations are due to abundance variations and (b) if they imply a variation in the detailed morphology (in L and, in particular, Teff) of one (HB ?) or more branches in the CMD, → one could **possibly** detect the "peculiarity" **also in the integrated** spectroscopy and (maybe) photometry if the "appropriate" bands are selected.

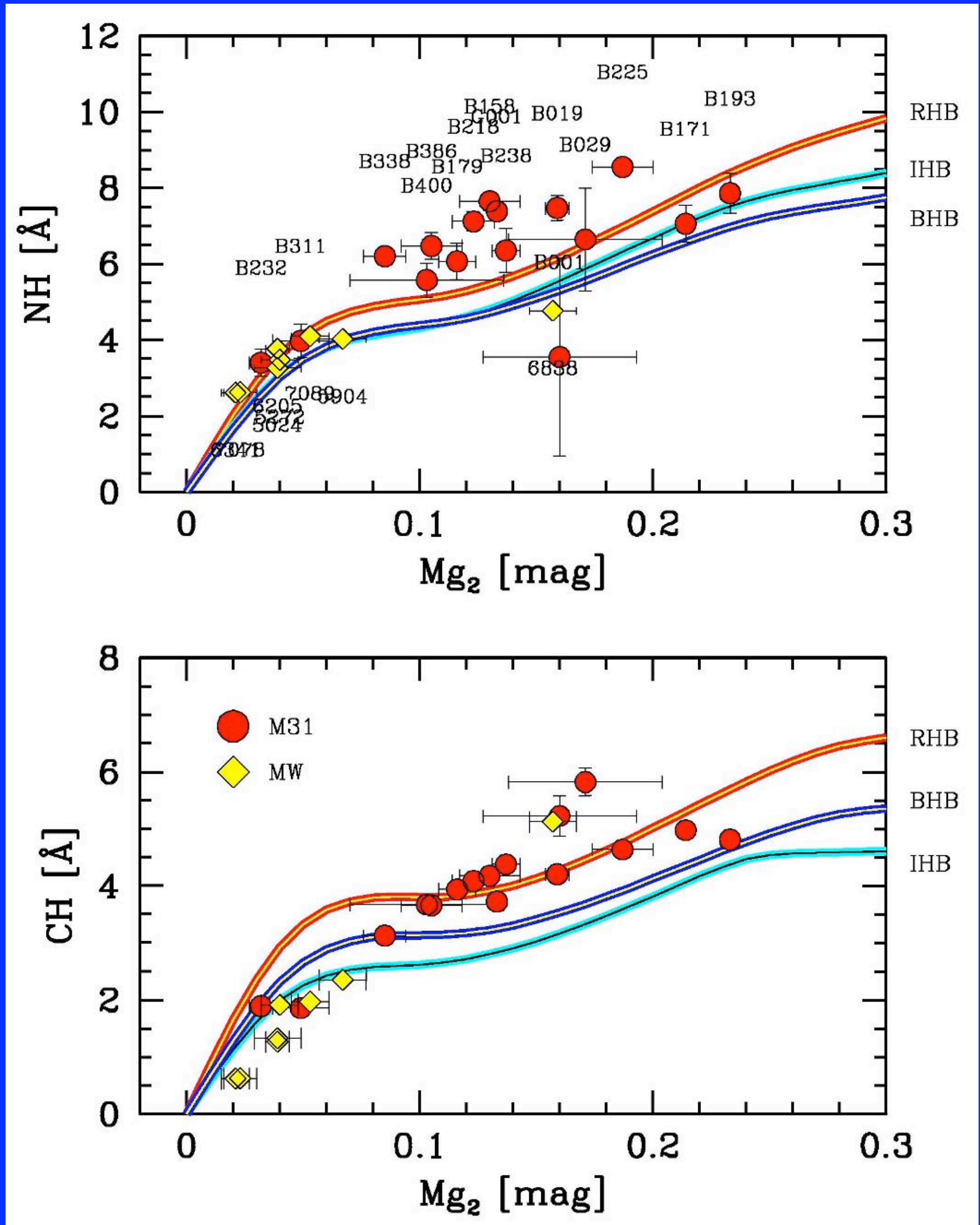
M31 GCs

HST


B158−G213
[Fe/H]=−0.74
B225−G280
[Fe/H]=−0.35
B386−G322
[Fe/H]=−1.09
B338−G76
[Fe/H]=−1.23
V
22
24
26
0
1
2
3
V−I

The NH-3360 feature





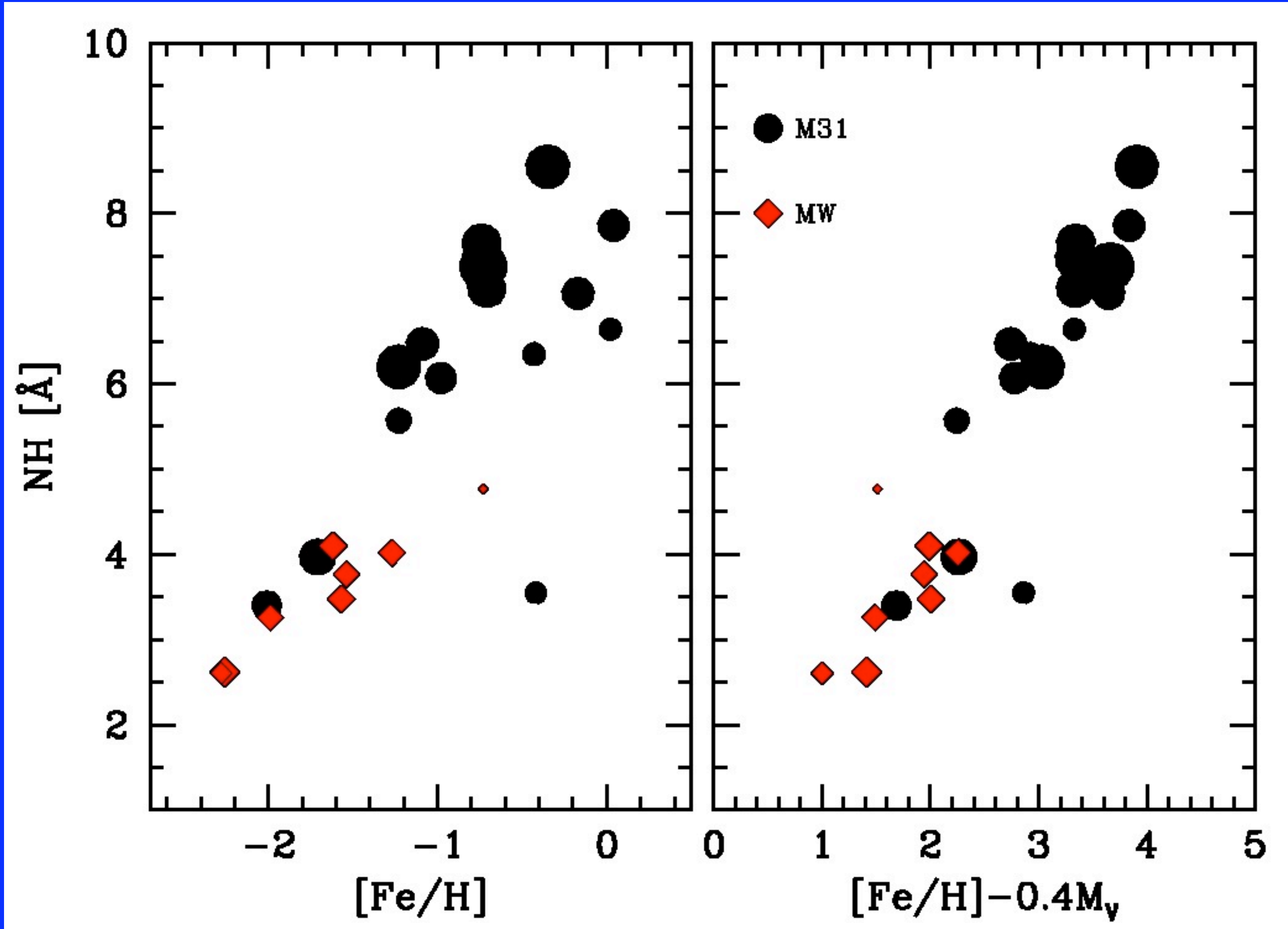
Li & Burstein (2003) Burstein et al. (2004)

N/C overabundance?

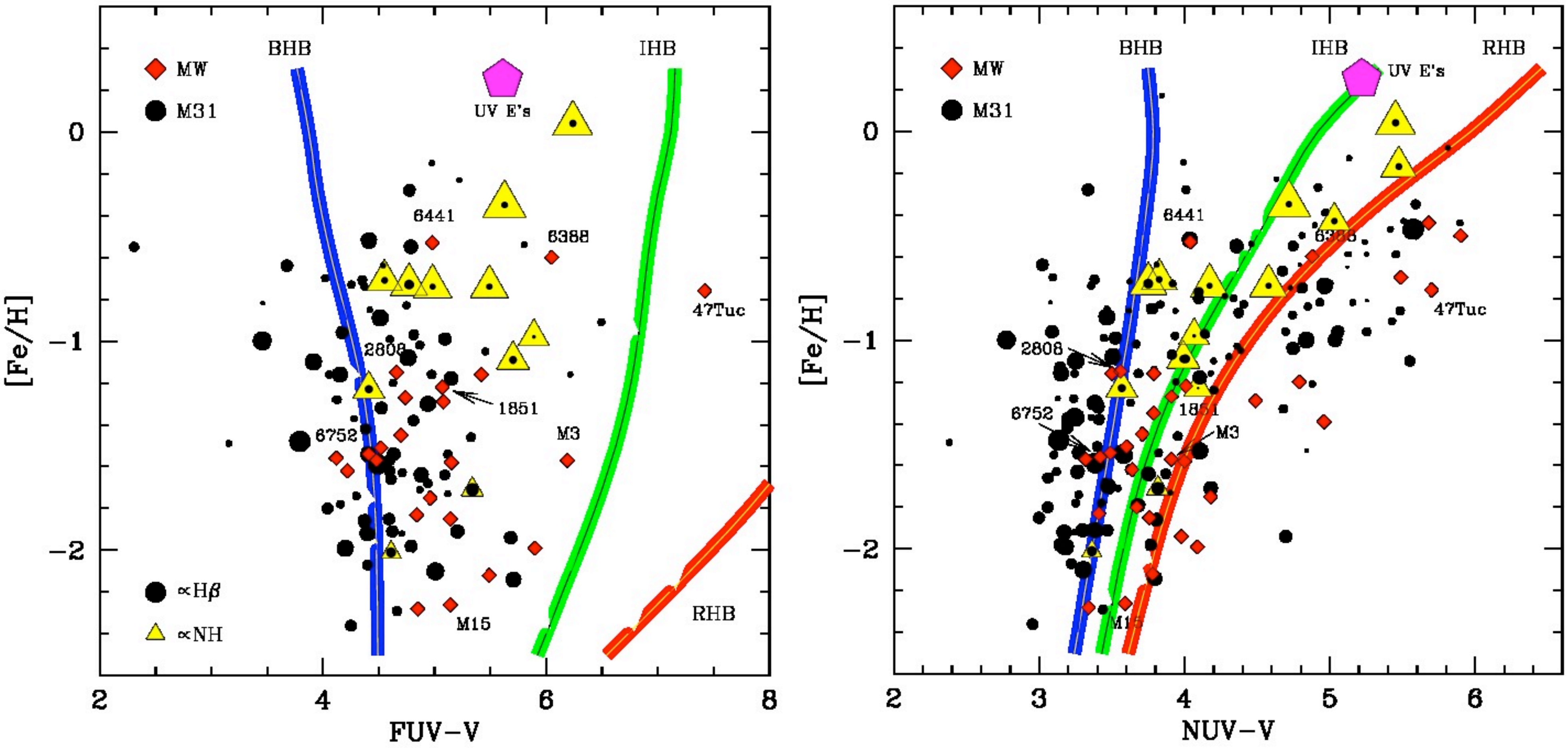
Burstein et al. (1984) noted a "peculiar" enhancement of the NH-feature ***in the integrated spectra*** of a small sample of very bright GCs in M31:

Since the NH 3360 Å feature directly deals with the N-abundance (Puzia et al 2005) a possible explanation could be that this evidence is due to N enhancements in the stellar population of the observed globulars (or in subsamples of their members?).

NH vs. Metallicity and …….



Hβ + NH


MW
M31
BHB
IHB
RHB
UV E's
6441
6388
47Tuc
2808
1851
6752
M3
M15
∝Hβ
∝NH
[Fe/H]
FUV−V
NUV−V

Speculation No. 2

- The N vs. He connection
- The link He-N does exit, but it is quite complex !!

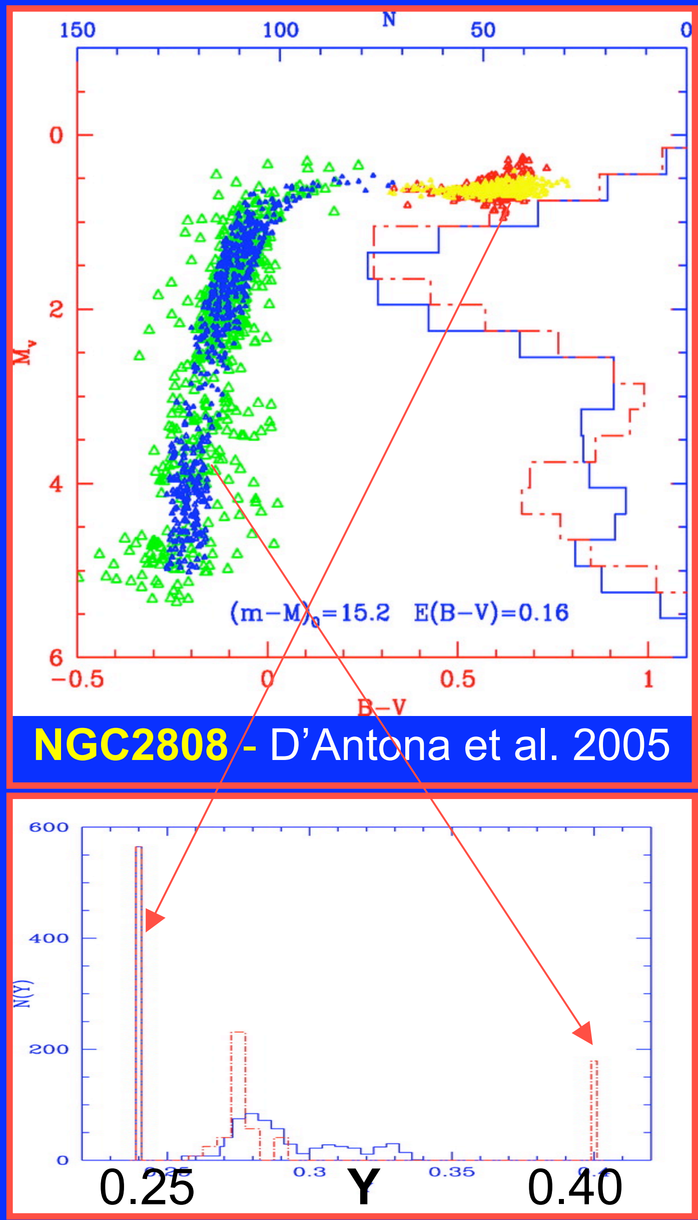
- The bulk of He is increased during the second dredge-up, which brings outward the He produced during the main sequence (Renzini 2008).

- N is not the best element to get estimates of true He-enhancement as a wide fraction of O could go into N, even at quite low temperature in low mass stars, without producing He.

- Al could be better, as it would require much higher temperatures (in the Mg-Al cycle) to burn…. But one must recall that the bulk of He is not produced in the same evolutionary stages as those leading to variations of elements such as N, O, Na, Mg, Al.

The impact of variations of the Helium abundance

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

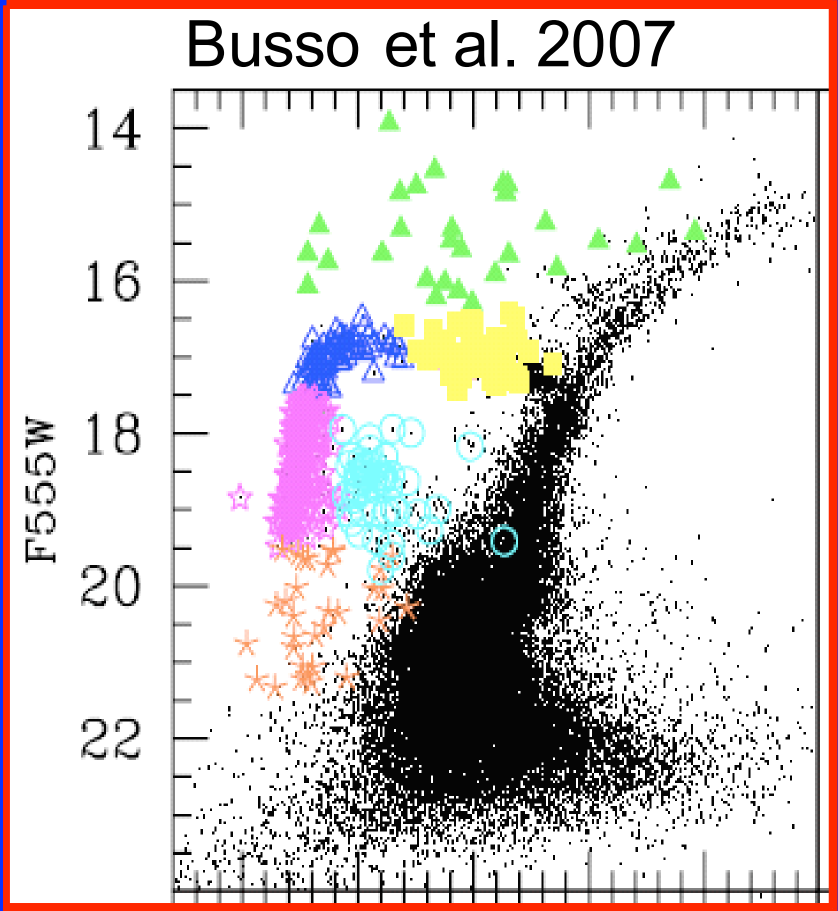


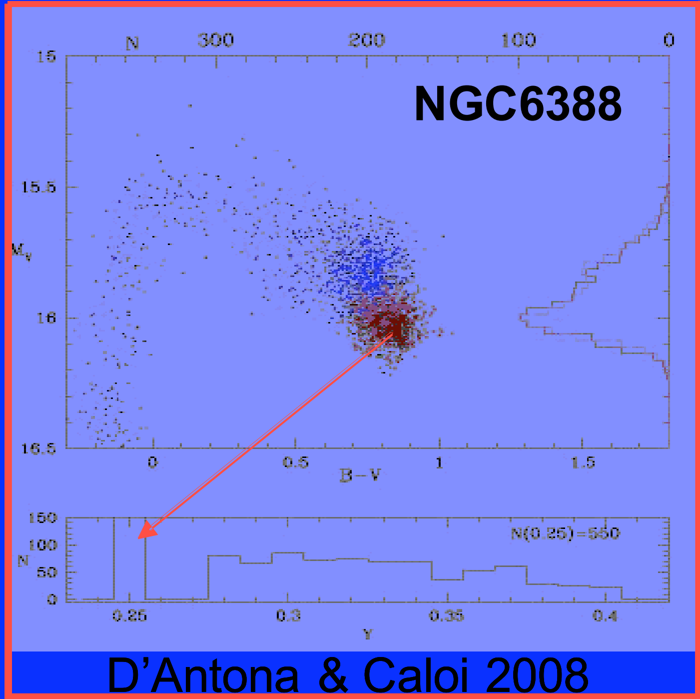
higher Y ⇒

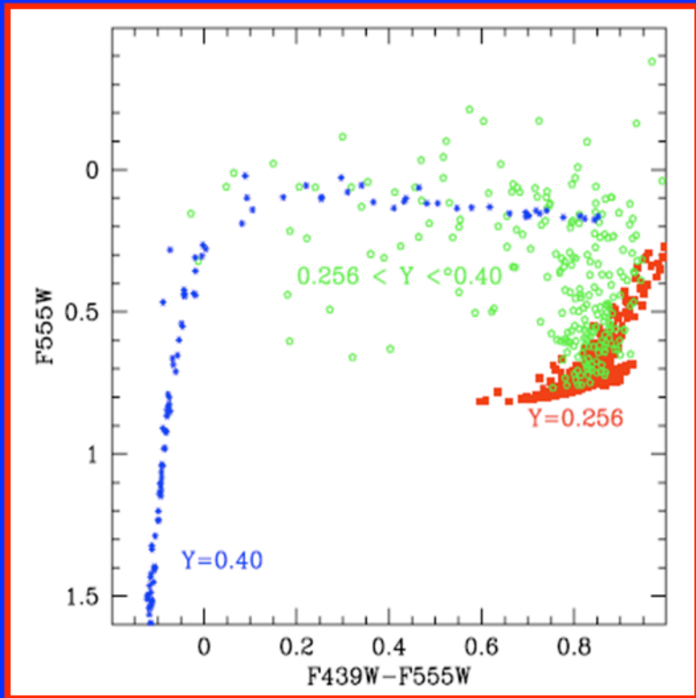
brighter HB
bluer HB

NGC 2808

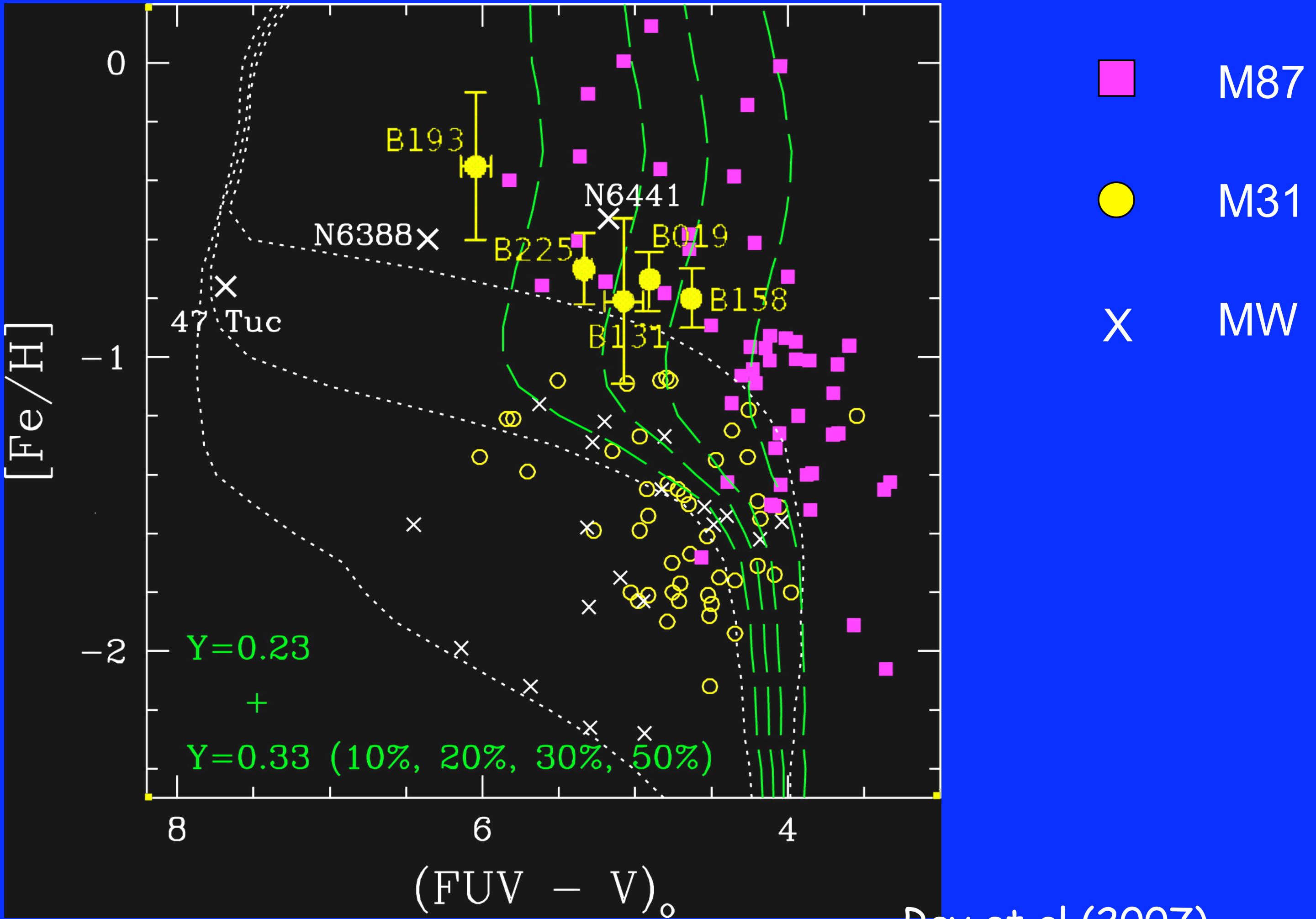
NGC 6388


Busso et al. 2007
F555W
14
16
18
20
22


NGC6388
N
300
200
100
0
15
15.5
16
16.5
0
0.5
B−V
1
1.5
150
100
50
N(0.25)=550
0.25
0.3
0.35
0.4
Y
D'Antona & Caloi 2008


F555W
0
0.5
1
1.5
0.256 < Y < 0.40
Y=0.256
Y=0.40
0.2
0.4
0.6
0.8
F439W−F555W

Helium-rich Globular clusters?



Rey et al (2007)
(adapted)

Conclusion No. 2

The available NH-3360 A observations in the integrated light of MW + M31 GCs seems be an "indirect" indication of the existence in these massive GCs in M31 (and maybe in M87?) of multiple populations of stars (He-enriched?) as detected from the spectroscopy and photometry of individual stars in several MW GCs

Predictions

- The HST CMDs of some of the brightest M31 GCs (e.g. B193, B225, B179, B19, B171, B238 etc.) observed to have strong NH-features should display long blue HB-tails, like NGC6441 and NGC6388 in the MW. B023 and B127 are predicted to have NH-strong + a blue HB-tail

- In turn, the spectra of the integrated light of NGC 6441 and NGC6388 should show a significant enhancement of the NH-feature if observed with the appropriate resolution

- If adequate observations of the integrated light of M87 GCs would display similar NH-enhacements, one could then interpret this peculiarity as an indirect suggestion that also in the brightest M87 GCs there are actually multiple stellar (sub)populations, maybe He-enriched

An alternative explanation

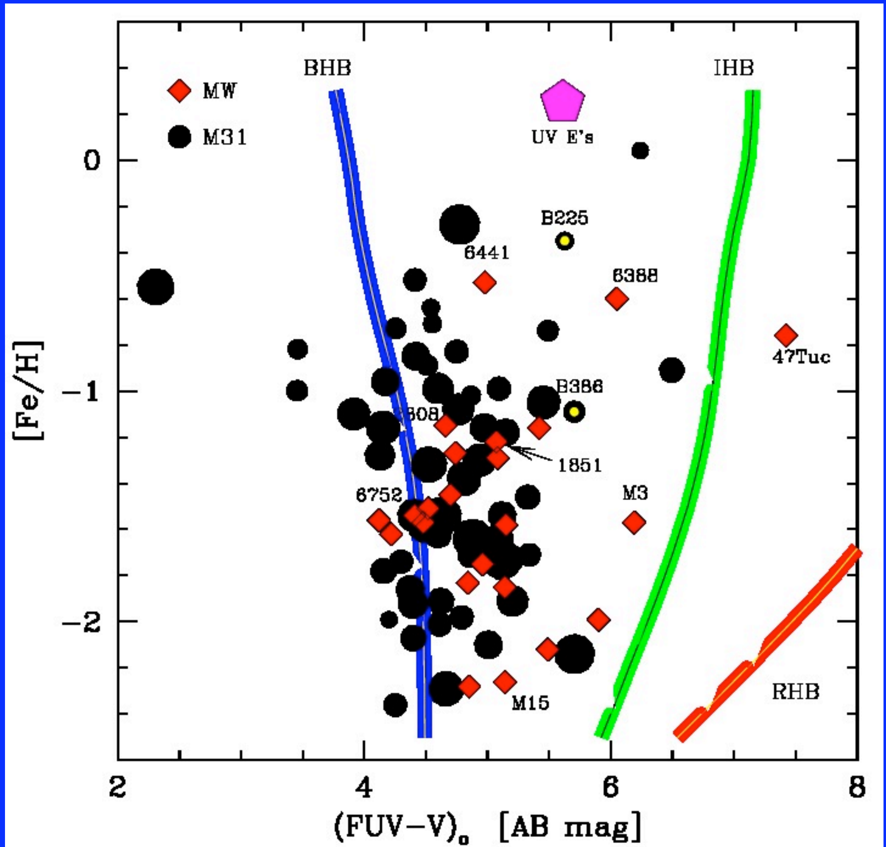
Buonanno et al. 1985 & Fusi Pecci et al. 1993

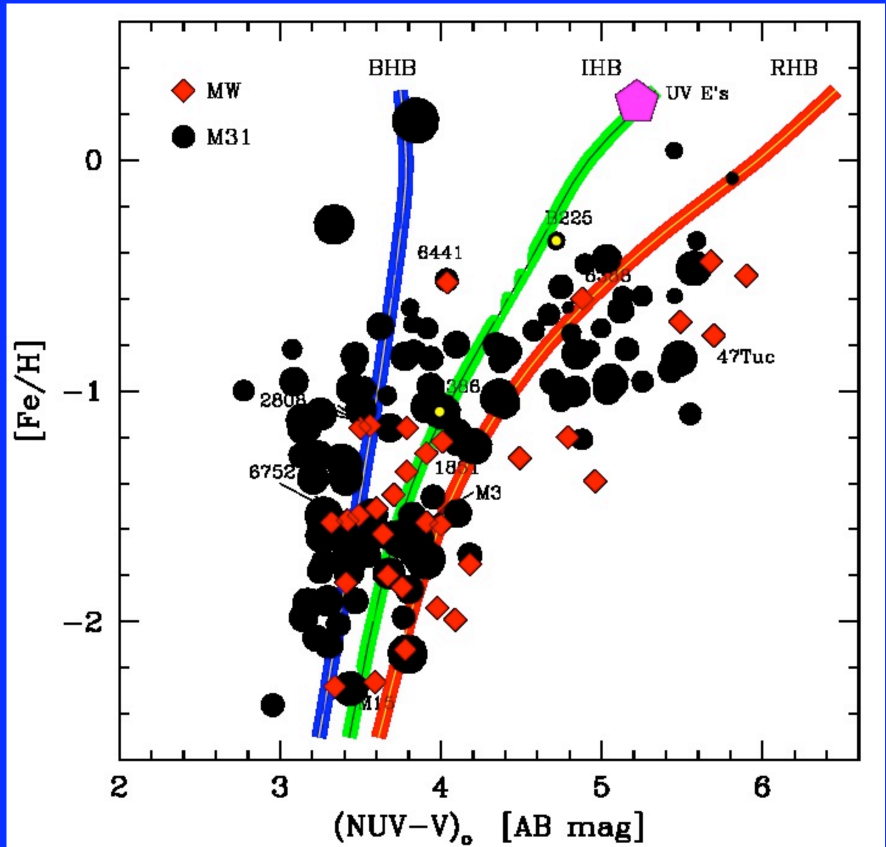
Suggested that the intrisic structural properties o the GC might influence the HB-morpholgy, i.e.: there is a possible connextion between stellar evolution and stellar dynamics

In particular, very high stellar density leads to increase mass loss from stars due to interactions (in the early GC stages), and this implies lower envelope mass on the HB and, in turn, bluer HB colors

Peacock et al. 2010 suggest now that the FUV-excess in the GALEX UV spectra of M31 GCs is actually due the high central density of these objects and, thus, to the existence of blue HB-tails

Dot-size ↑ if GC concentration ↑





Conclusion on the …2° parameter

- Most of recent studies converge to the conclusion that more than two parameters (furthermore interacting among themselves) are actually involved in the description of the HB-morphology….
- A third parameter is needed, at least !!

- Since total GC luminosity, high central density and concentration are actually, at bottom, all related to the (present and/or original) total mass, i.e. to the depth of the gravitational well, and, in turn, to the ability to keep inside the GC itself the mass lost by the member stars, **one could conclude that:**
  - **the depth of the central well is probably**
  - **the "real" third parameter**

Final question

Any impact on cosmology?

Should we worry about?

A few basic relations

- $t \rightarrow 1/(\mu^4 \; M^2)$
- $T_{eff} \rightarrow M^{0.5} \mu$
- $t \rightarrow 1/(\mu^2 \; T_{eff}^4)$
- $\mu = 1/(2X+3/4Y+1/2Z)$

	Y = 0.24	Y = 0.40
μ	0.600	0.695
age	14 Gyr	7.8 Gyr
Teff	6000°K	6960°K
LogTeff	3.78	3.84
SpTy(TO)	G2	F5

General Conclusions

- As shown for NGC 6441 & 6388, **there is a quite wide group of metal-rich GCs in M31 which share the UV-excess + BHB anomaly**
- Most of **these objects are** among the brightest metal-rich GCs in M31, brighter (i.e. **more massive) than ω Cen** in the MW
- Coupling UV-GALEX and NH-3360 A observations in the integrated light of MW + M31 GCs one might conclude that **in M31 GCs (and maybe in M87?) there is an "indirect" indication of the existence of multiple populations of stars (He-enriched?)** as detected from the spectroscopy and photometry of individual stars in several MW GCs
- **This evidence could ask for a deeper study of the impact of a possible "age-metallicity-helium" degeneracy in the cosmological use of stellar population syntheses**

- Fine
- ciao ciao

ALL GLOBULAR CLUSTERS SHOW

Unambiguous (photometric) evidence

of Multi-Populationss in

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

… very massive GCs …..

Unambiguous (spectroscopic) evidence

of Multi-Populations in

all clusters studied

… intrinsic property …

The HB Morphology

Fusi Pecci & Bellazzini 1997

- Five items were especially noted, and frequently forgiven later:

- The HB is not an evolutive sequence, but simply a narrow, composite locus, like ”a beach, where all stars go to take a bath”.
- The (color) temperature shift along the Zero Age HB is strongly dependent on mass loss and is highly non-linear with varying metallicity (Z) and helium (Y): Teff = f(Z,YMloss). Mass loss is a crucial phenomenon which drives the actual location of the HB in color. In particular, ”why, when, where, how much, and how long mass loss does take place before the HB matters very much”.
- The total metallicity (Z) is the “first” intrinsic parameter which drives the HB morphology: High-Z implies Red HBs, Low-Z implies Blue-HBs, BUT a “second parameter” -2ndP (at least) is necessary to properly rank the observed CMDs.
- Important efforts to yield a systematic parametrization of the observed HBs were made during the early ’70s. One can easily ascertain that the essence of the problem was already set on clear grounds f.i. by Rood (1973), and various 2ndP−candidates were proposed (age, helium abundance, CNO, core rotation, GC intrinsic structure, orbit, etc.).
- Any mechanism (intrinsic or induced) which could somehow affect, during any evolutionary stage, the core, the envelope and/or total mass of the star may play a rˆole in the 2ndP−game because of the exceptional sensitivity of HB stars to any tiny variation.

Speculation No. 1

•It is now widely accepted that stellar populations in MW GCs are probably selectively enriched in helium (even up to very high values)

•The brightest (more massive) MW GCs (in particular, but not exclusively) display "peculiar" morphologies of the main branches in the CMD (MS, RGB, HB…) when observed with the appropriate (very high) photometric and spectroscopic accuracy and appropriate filters (UV,B, Stromgren, SLOAN, etc.)

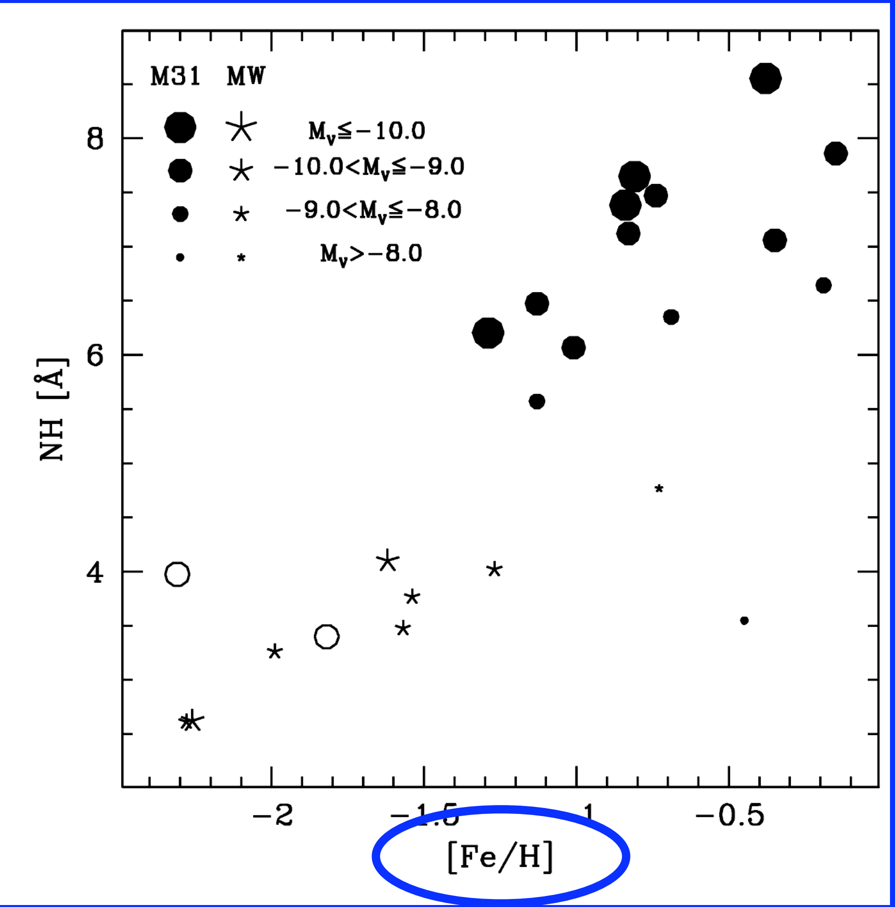
•It is obvious that the best tool to detect such "peculiarities" is to secure photometry and spectra of the individual stars in as many clusters as possible

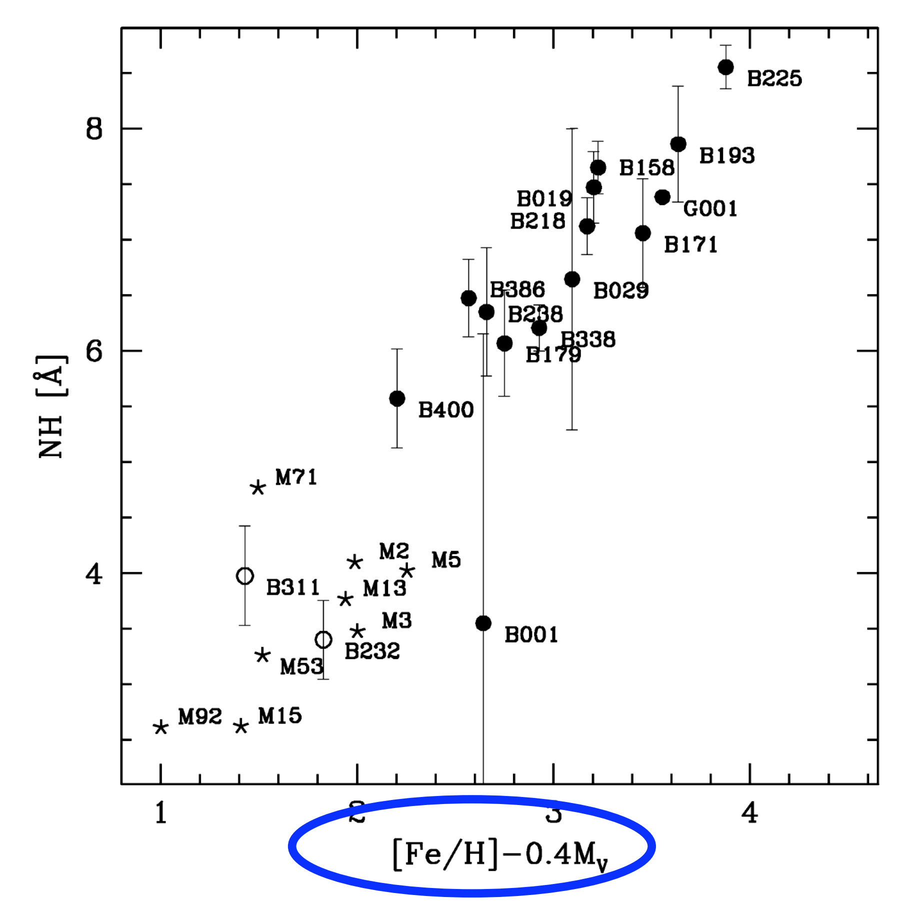
•However, it is also conceivable that, (a) if the star-to-star variations are due to abundance variations and (b) if they imply a variation in the detailed morphology (in L and, in particular, Teff) of one (HB ?) or more branches in the CMD, → <u>one could possibly detect the "peculiarity" also in the integrated spectroscopy and (maybe) photometry if the "appropriate" bands are selected.</u>

Ammasso globulare gigante in M31

Gli ammassi globulari

Let's plot the data ....





But ……… GC $\neq$ SSP

There are binaries, blue stragglers …primordial, collisional..

Not all stars have same initial chemical composition (Z and/or Y)

Not all stars are strictly coeval

N vs. He

- non esiste una chiara referenza che metta in diretta relazione l'elio e l'azoto (come rappresentante delle variazioni degli elementi leggeri proton-capture).
- perche' (ed e' vero) il grosso dell'elio non viene prodotto nella stessa fase evolutiva che produce le variazioni di elementi come N, O, Na, Mg, Al.
- Il grosso dell'He e' quello che viene dal second dredge-up che porta su He prodotto in main sequence (vedi Renzioni 2008).
- Invece gli elementi leggeri vengono modificati dall'hot bottom burning in AGB, se uno crede che i polluters siano le AGB di massa intermedia, alla d'antona. In questo caso, le variazioni di O, N, Na etc. possono essere anche grandi, ma la produzione di He e' piccola.
- Ovviamente le stelle che fanno HBB sono anche quelle che hanno il 2nd dredge-up e questo da‘ una corrispondenza, quindi. anche nel caso delle fast rotating massive stars (alla decressin-charbonnel), in cui le variazioni sia di He che di elementi leggeri sono prodotte in main sequence, i due fenomeni sono fatti in regioni leggermente diverse.
- Comunque, l'N non e' il miglior elemento, perche' basta una temperatura relativamente bassa per bruciare quasi tutto l'ossigeno in N, temperatura raggiunta anche da stelle di bassa bassa, che quindi non fanno molto He. L'Al andrebbe meglio perche' richiede temperature (masse) molto alte, per essere prodotto nel ciclo MgAl, quindi in quel caso hai una migliore certezza che alto Al implichi probabilmente alto He.
- Riassumendo, la corrispondenza He-N c'e', ma e' piu' complicata