The Horizontal Branch morphology and the UV properties of old stellar populations

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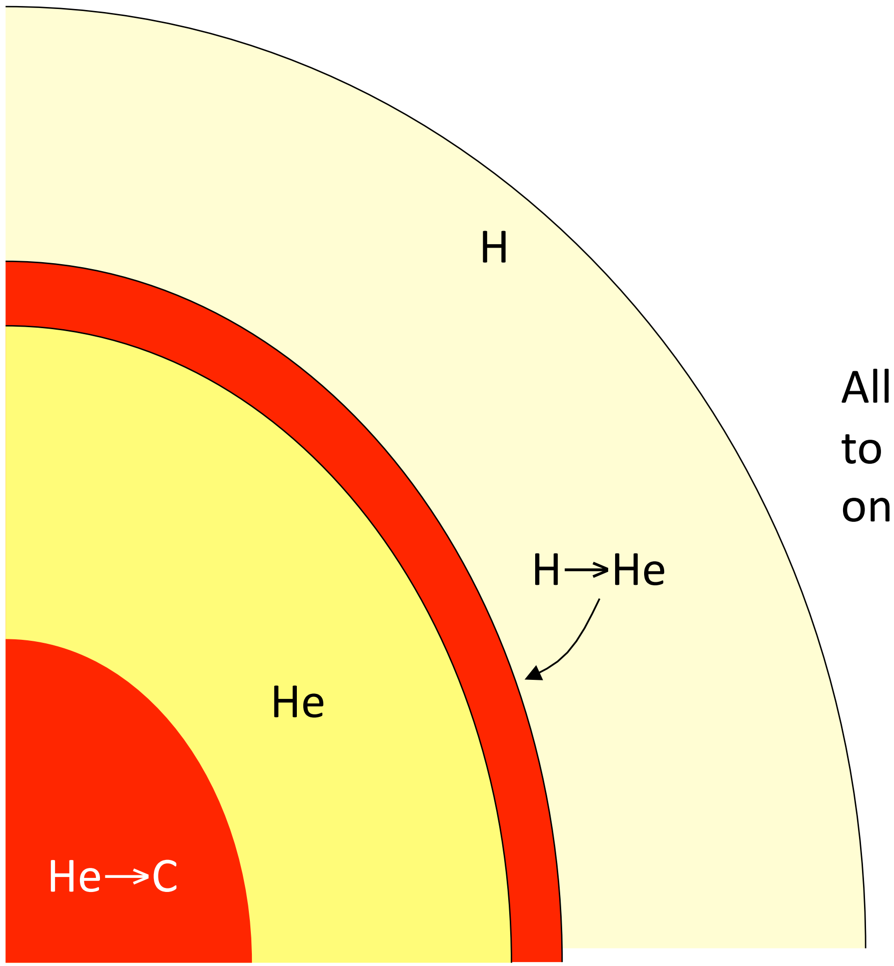
OUTLINE

1. Introduction
2. The role of internal He variations
3. An empirical Mass Loss law
4. The HB morphology in extra-galactic GCs
5. Summary

1. What are HB stars?



(1) He → C in the CORE

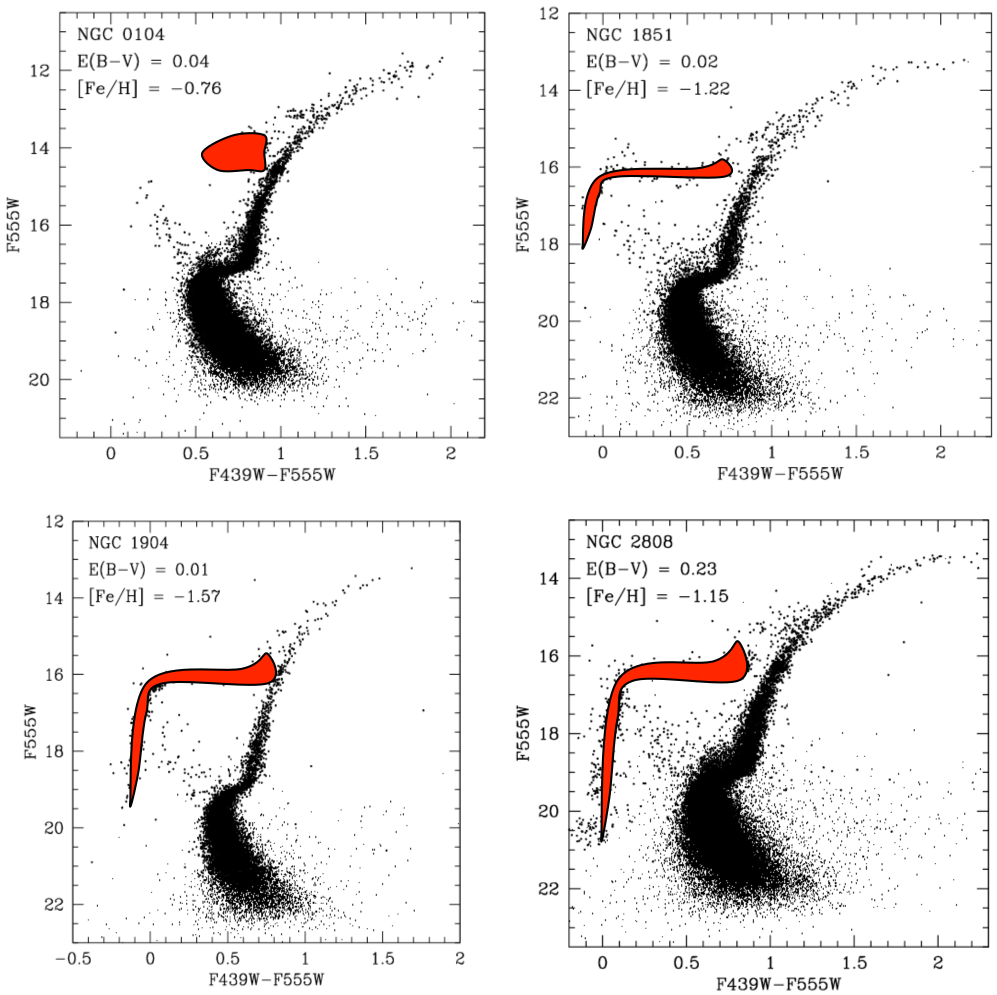
(2) H → He in the SHELL

Hoyle & Schwarzschild 1955

All stars with initial total mass M > 0.5 M_o are able to attain the thermal conditions required for the onset of the He-burning.

I will consider only low-mass stars

1. What are HB stars?

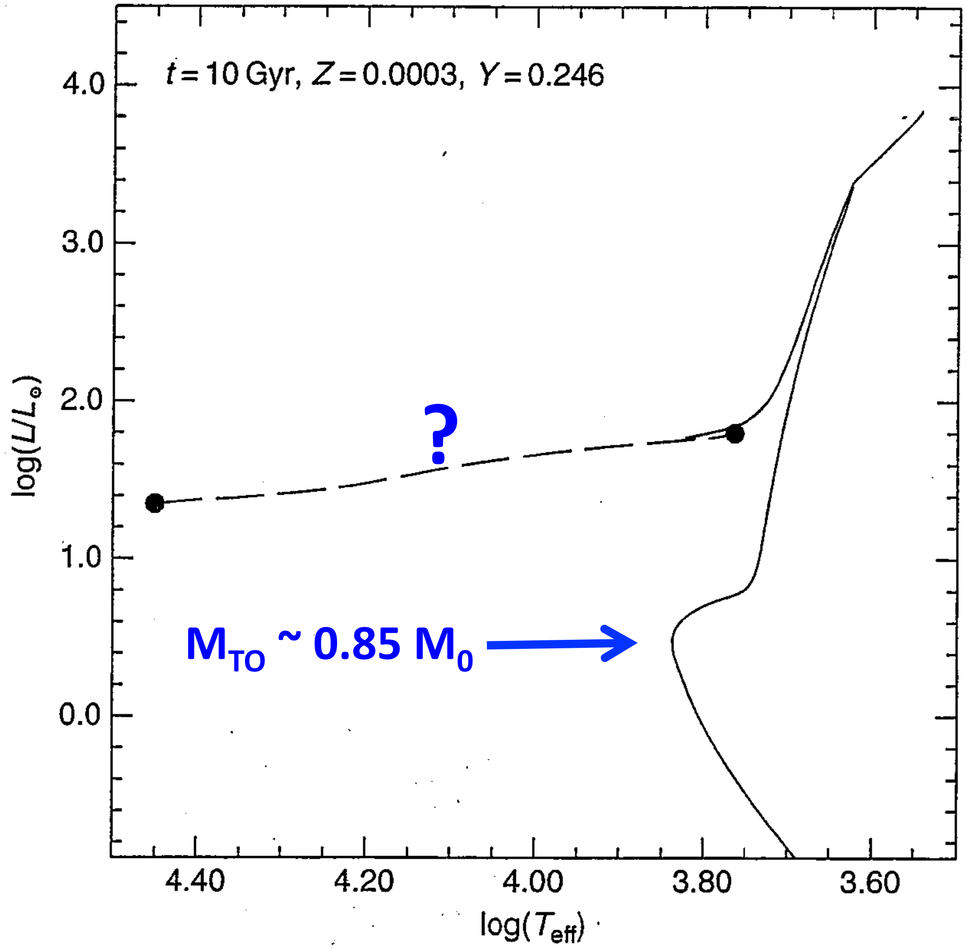


HB stars do not follow an horizontal distribution in observed CMDs

They show very different extensions and different distributions

Piotto et al. 2002

1. What drives the HB morphology



The location (T_{eff}) of a star along the ZAHB depends on its mass,

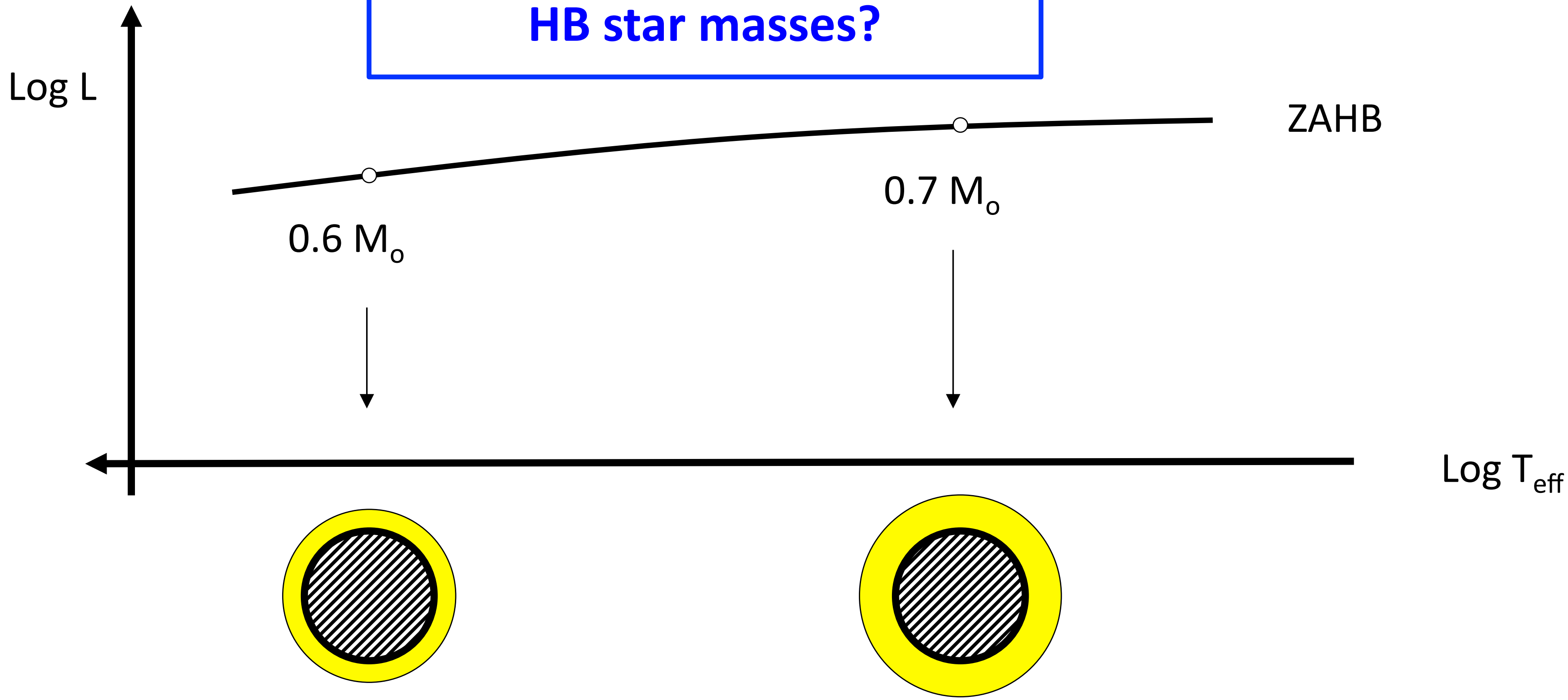
For low-mass stars (M_i<2.2 M_0) the mass of the core is only weakly dependent on the total mass

For M_i < 2.2 M_o → M_c ~ 0.5 M_o

$$q = \frac{M_C}{M}$$

1. What drives the HB morphology

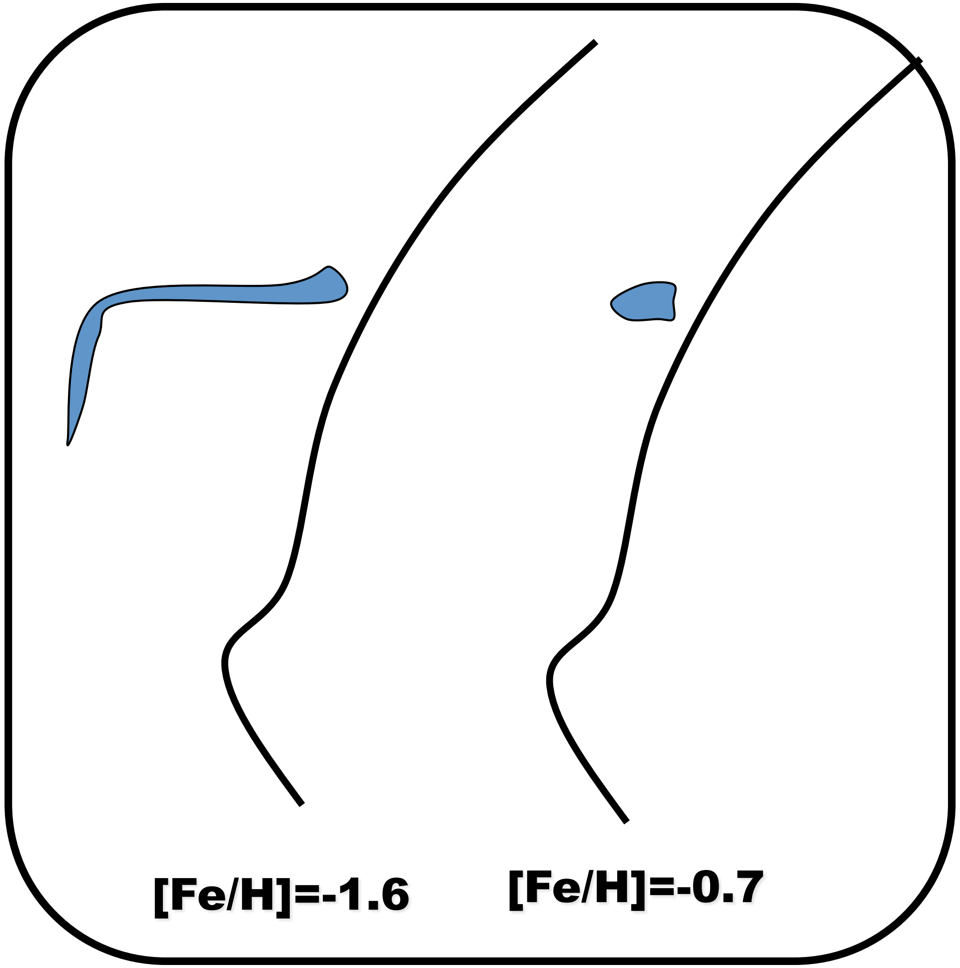
What causes the variation of HB star masses?



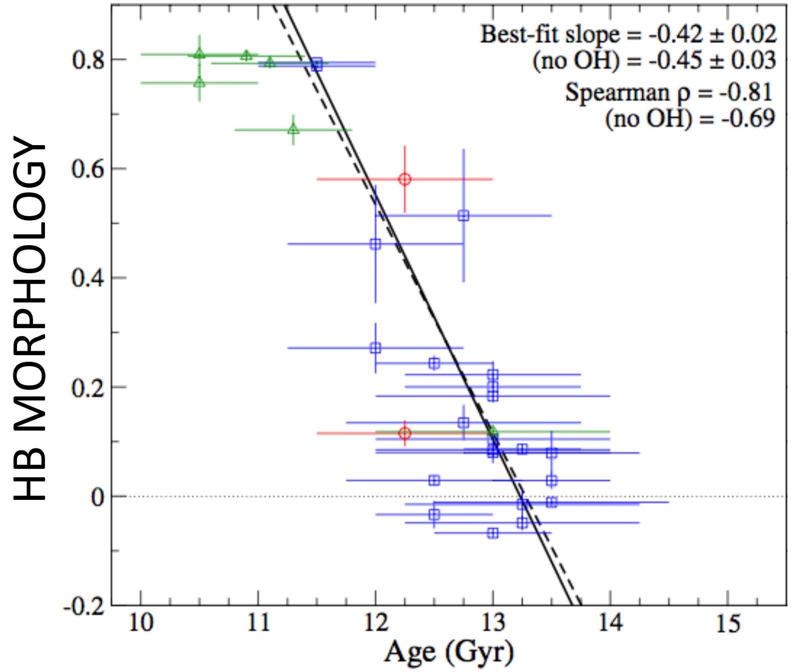
There are many culprits that can affect the temperature distribution of HB stars: metallicity, age, mass-loss, He abundance, stellar rotation …

1. What drives the HB morphology

Metallicity is the first parameter



Age is the second

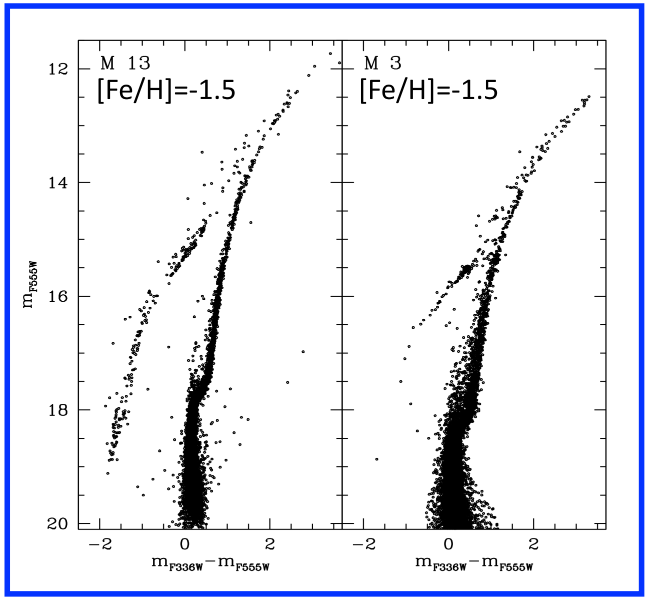


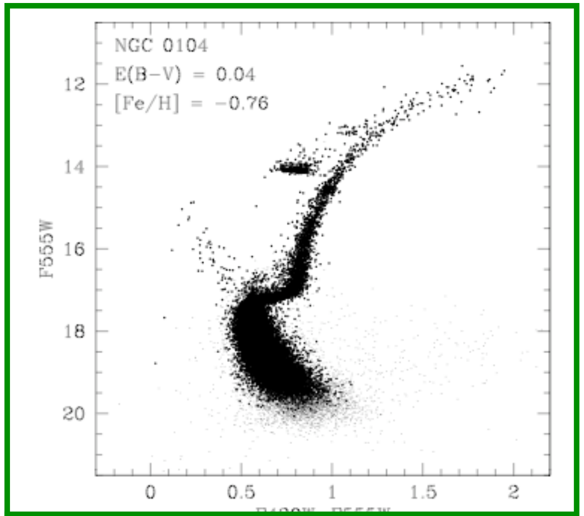
Gratton et al. (2010); Dotter et al. (2010)

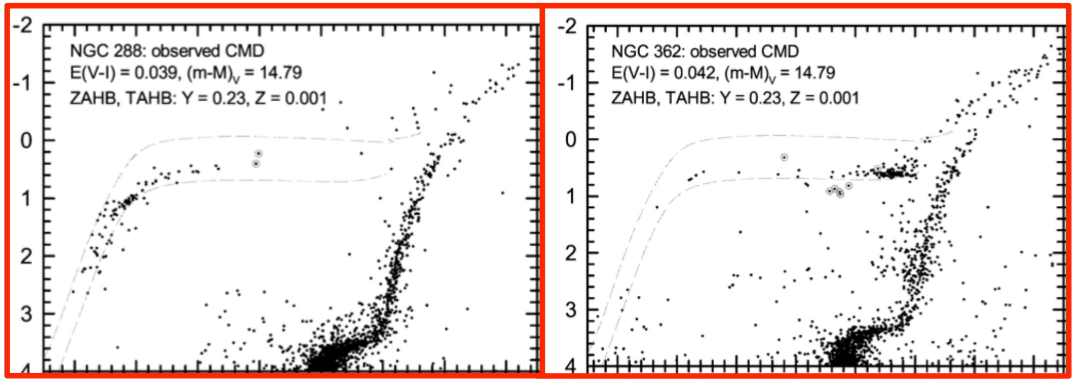
1. What drives the HB morphology

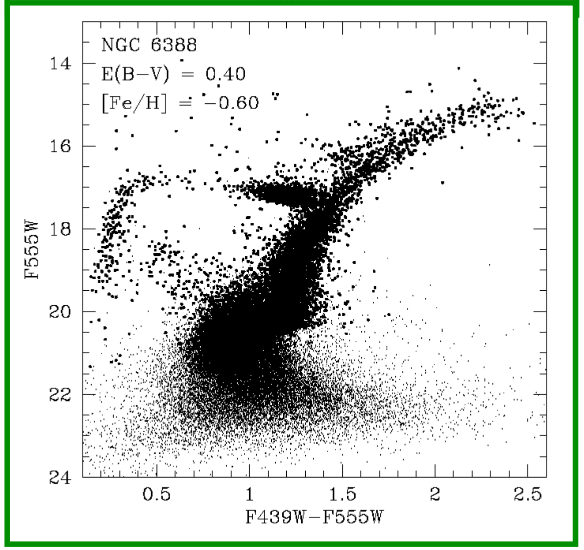
They fail in many cases!

For a review Catelan 2009, Gratton et al. 2010; Dotter et al. 2010









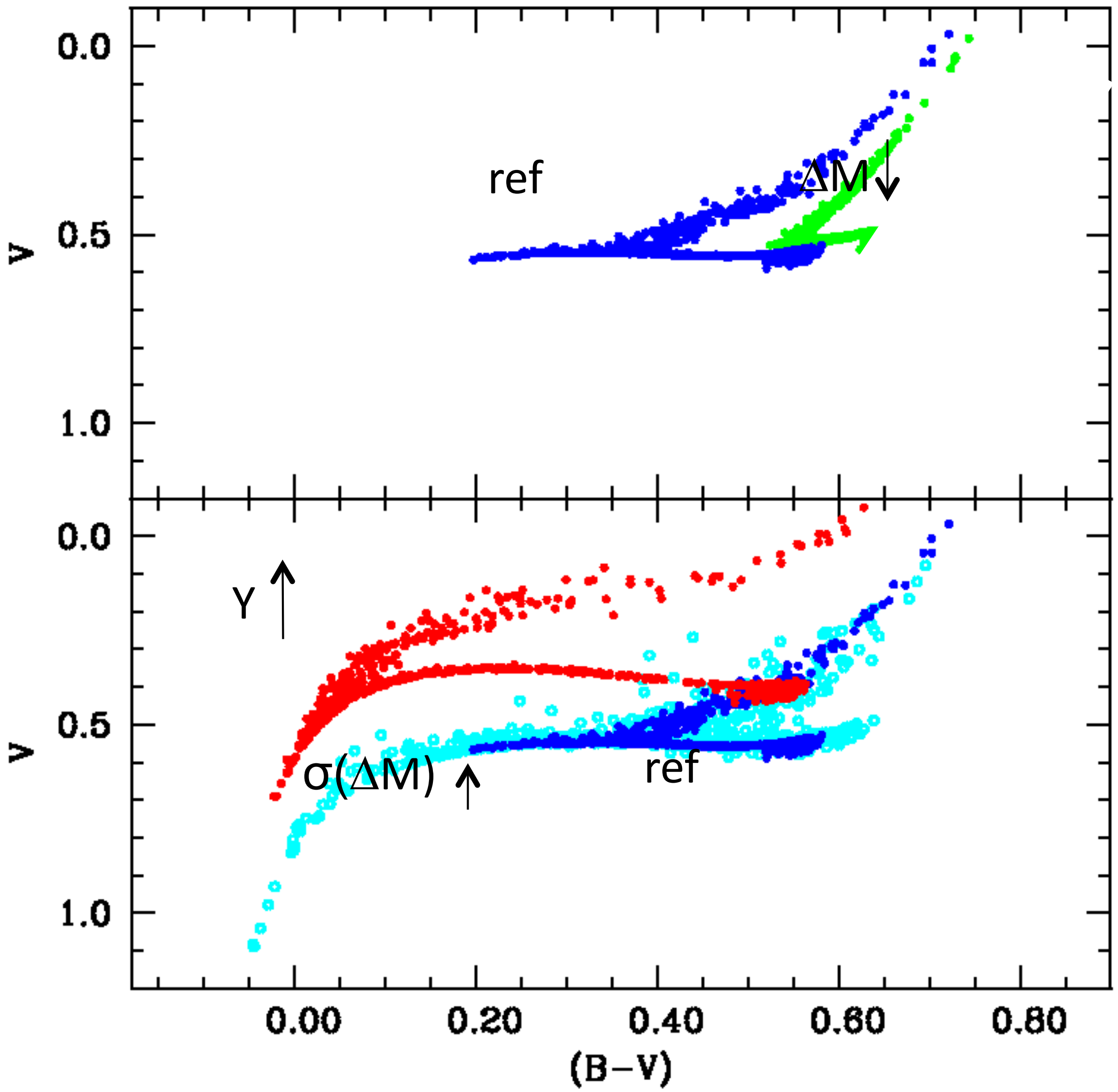
1. What drives the HB morphology

Fixed parameters:
Z
Age (M_{RGB})

σ(ΔM) = mass loss dispersion

Y

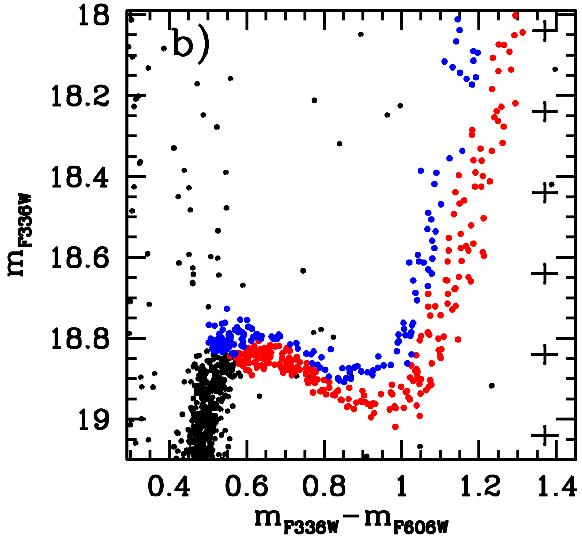
ΔM = RGB total mass loss



2. The role of He

2. The HB in the context of MPs

RGB splitting

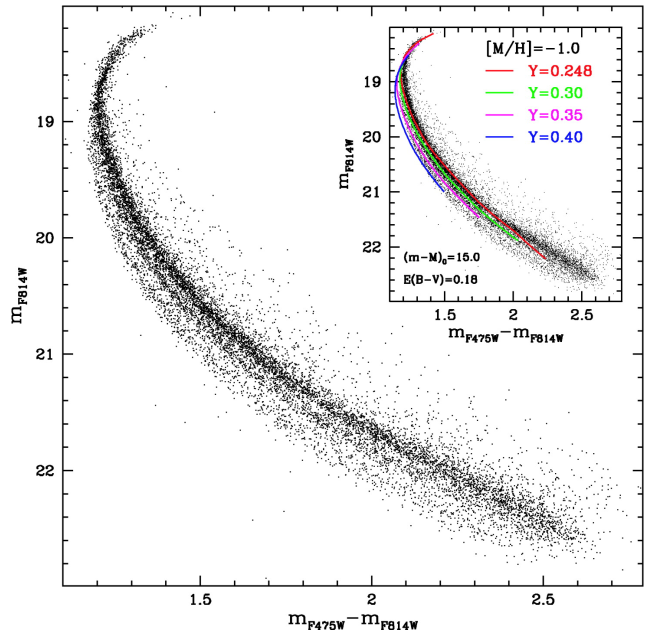


Dalessandro et al. 2014

For a review about **"Self-enrichment"** in GCs see

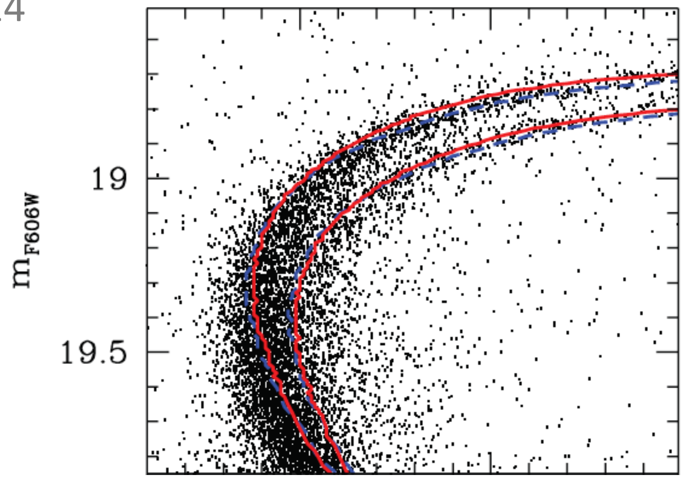
Decressin et al (2002); Ventura & D' Antona (2008); De Mink et al. (2009)

MS splitting



Piotto et al. 2007

SGB splitting



Cassisi et al. 2008

2. Internal He variations and the HB

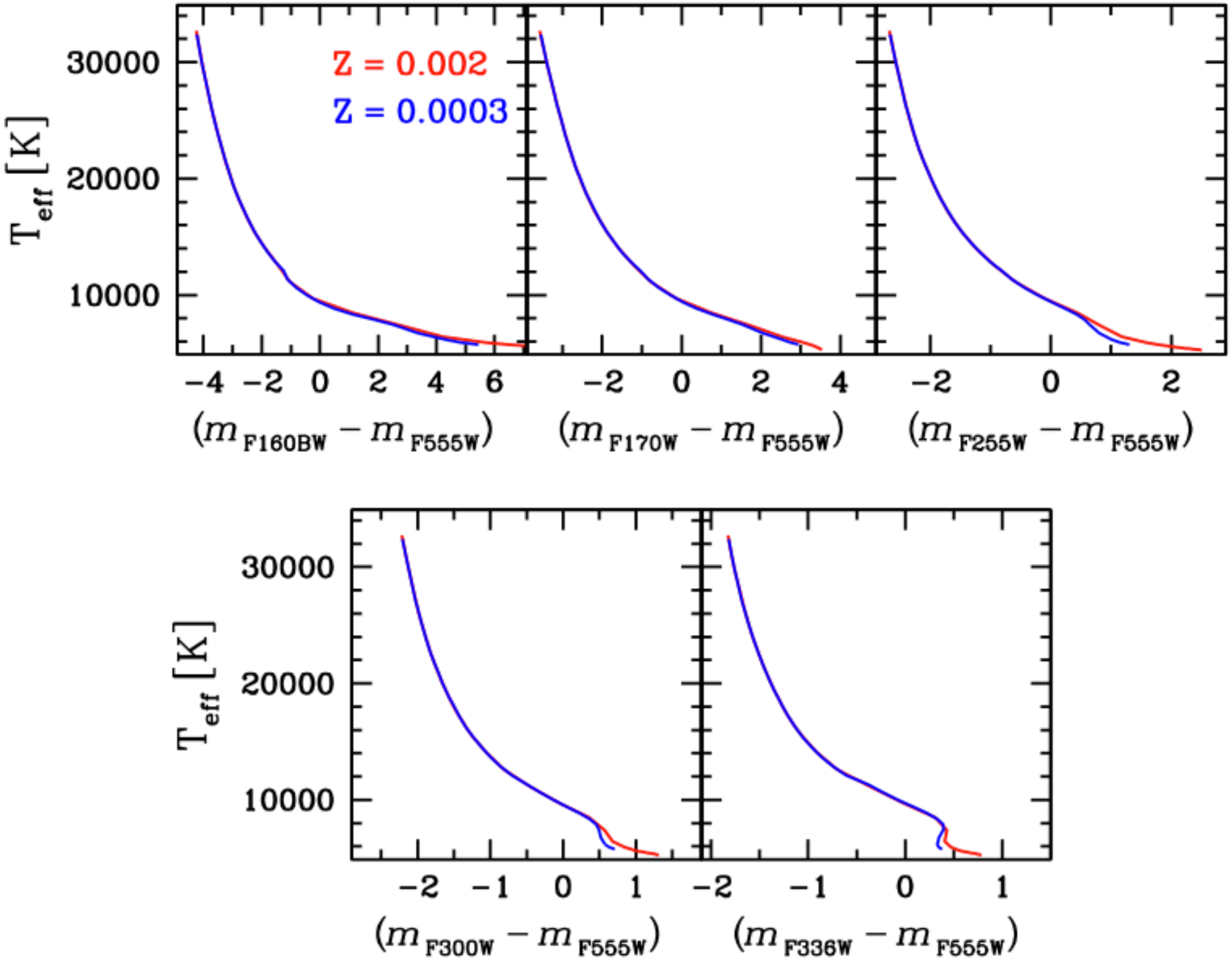
1. High quality UV and optical photometry

2. A set of isochrones and HB tracks for different metallicities and Helium abundance (BaSTI; Pietrinferni et al. 2006)

3. Take into account the effect of radiative levitation (BC for [Fe/H]=0.0/0.5 for T>12000K; Behr et al. 2003; Pace et al. 2006)

4. An extensive use of synthetic HBs obtained with two free parameters: ΔM and $\sigma_{\Delta M}$ (Y_{max}, ΔY)

2. The Horizontal Branch in UV

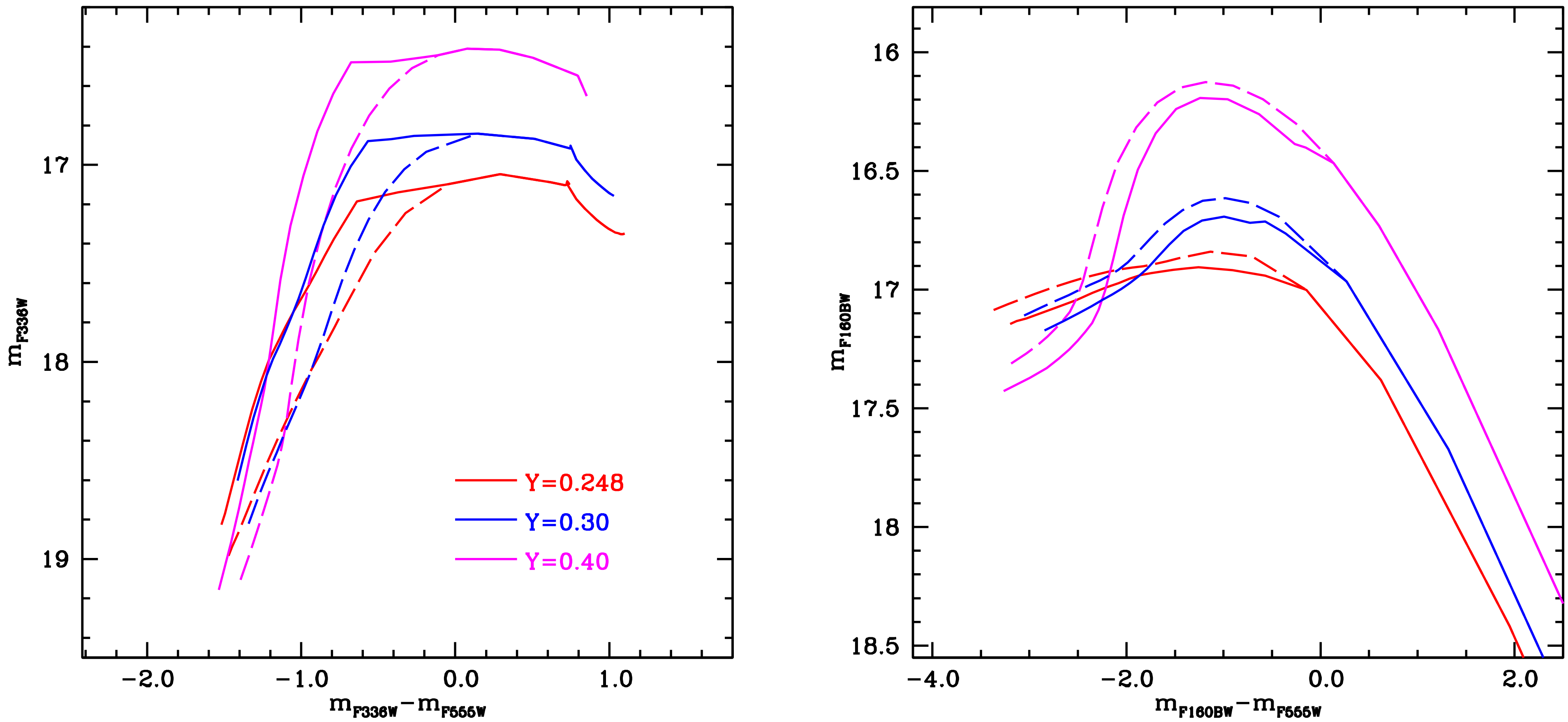


THE BEST APPROACH IS THE COMBINATION OF OPTICAL AND FAR UV DATA

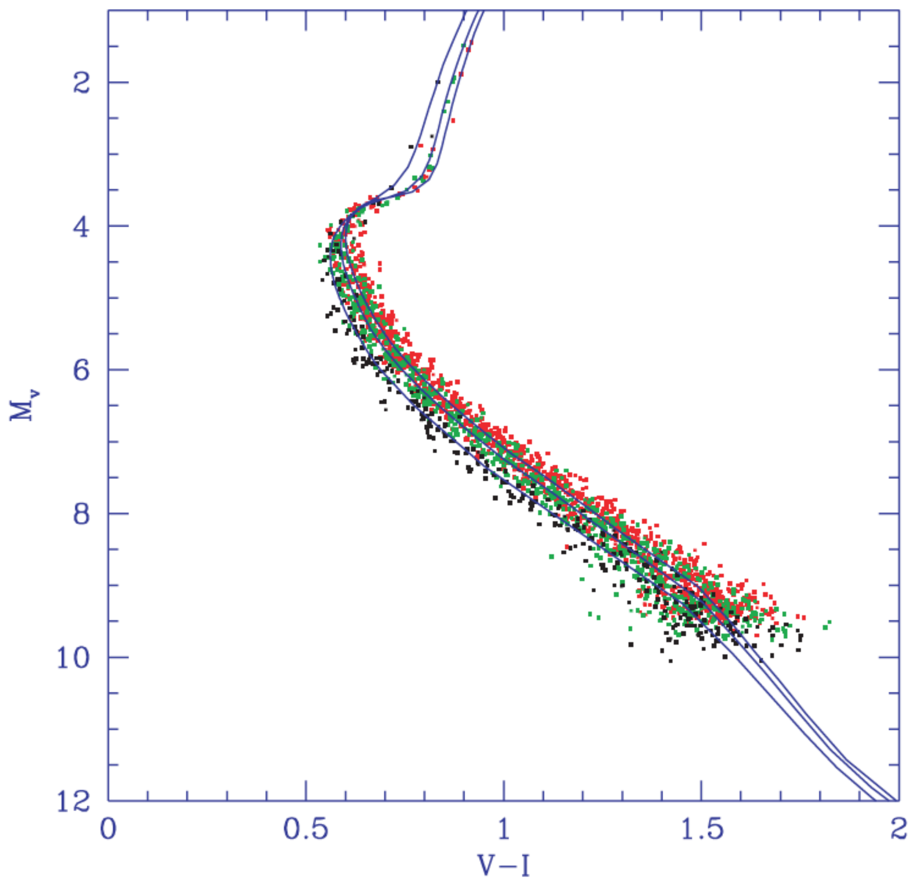
(FUV-V) COLOR IS MORE SENSITIVE TO T_{eff} VARIATIONS

2. The Horizontal Branch in UV

Dalessandro et al. 2011



2. The Horizontal Branch in UV: NGC 2808

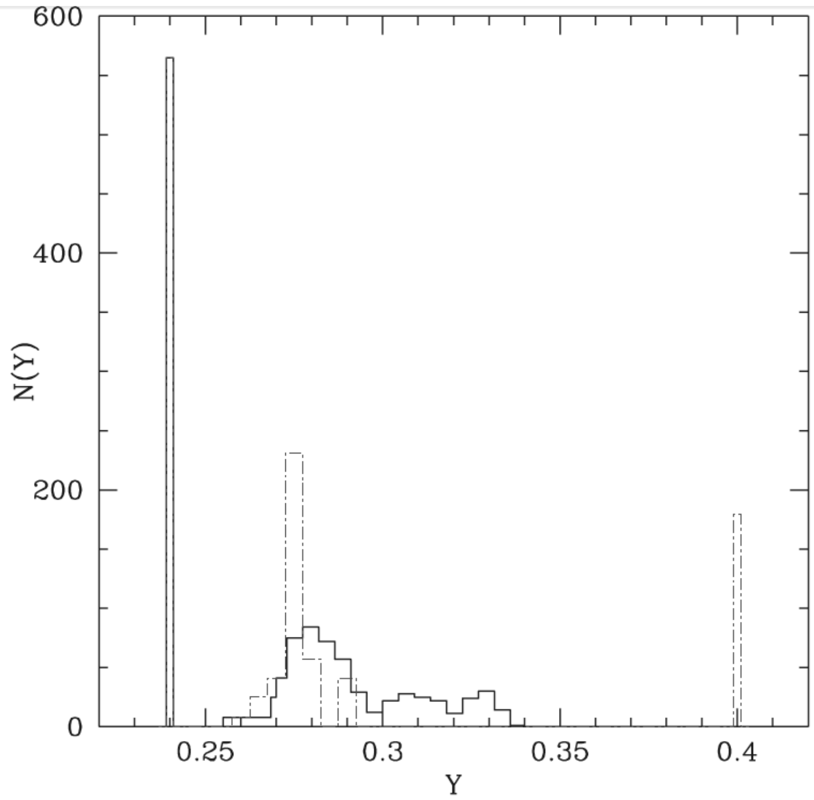


D’ Antona et al. (2005, 2008)

Y=0.248 **Y=0.30** **Y=0.40**

3 sub-populations with different He abundances have been observed from both photometric and spectroscopic analysis

(Piotto et al. 2007; Bragaglia et al. 2011; Pasquini et al. 2011)



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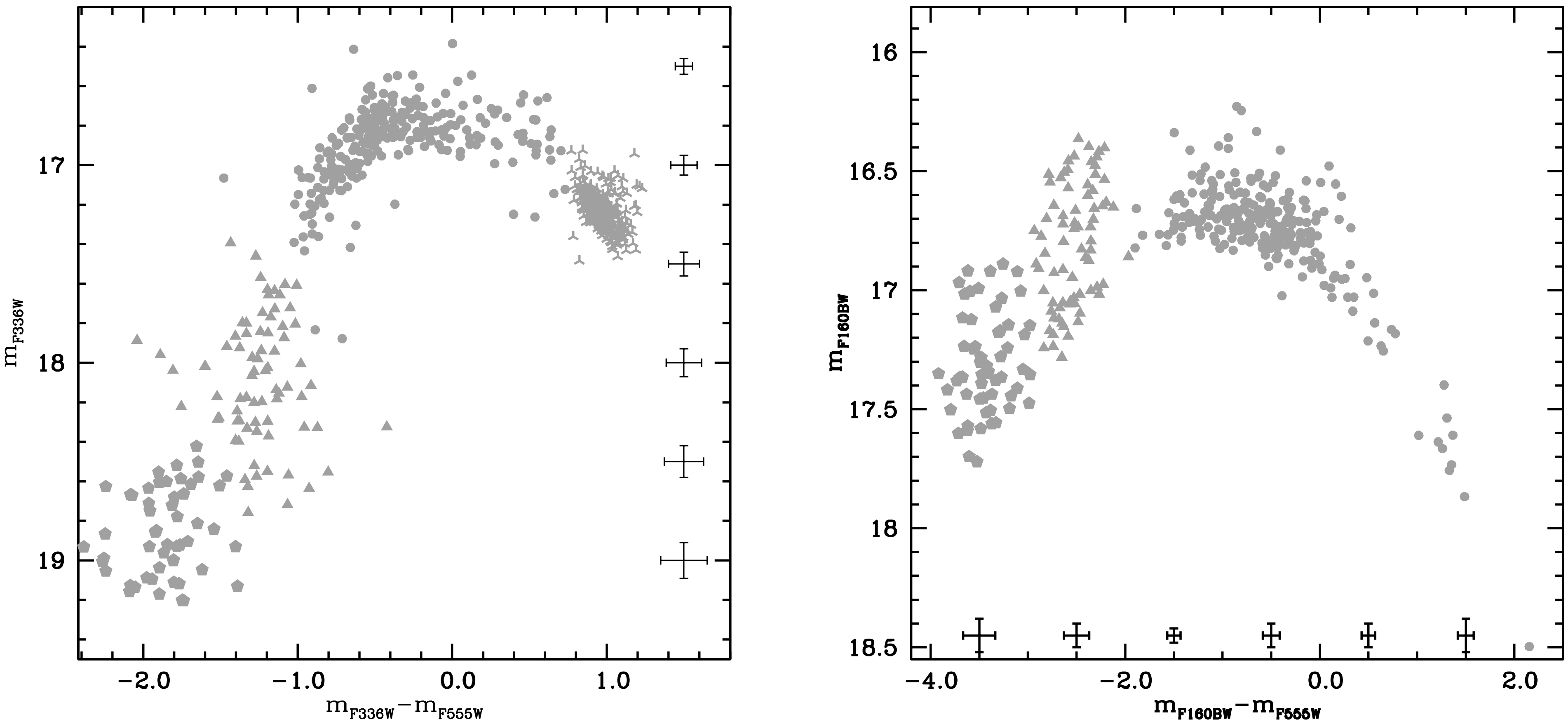
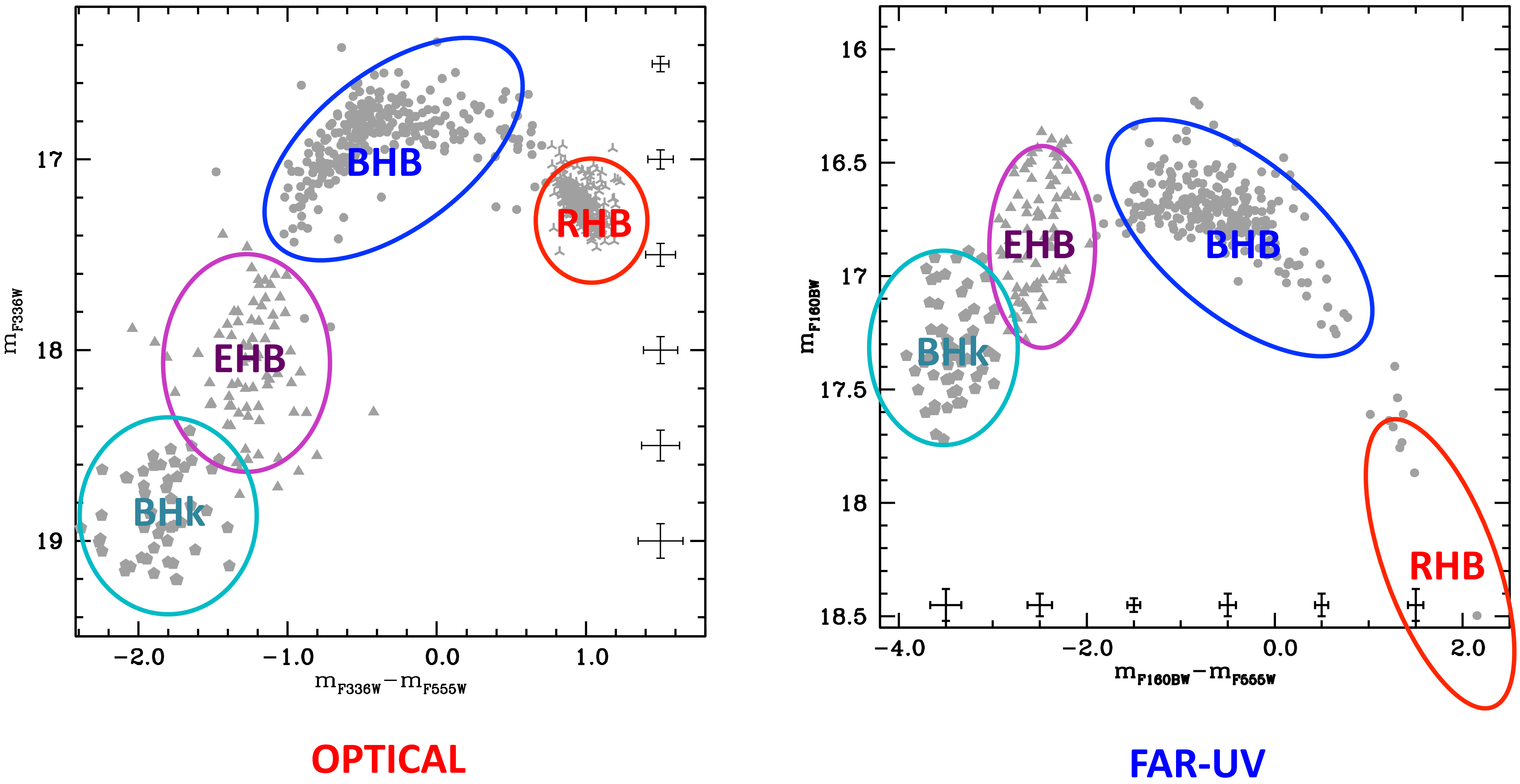


OPTICAL

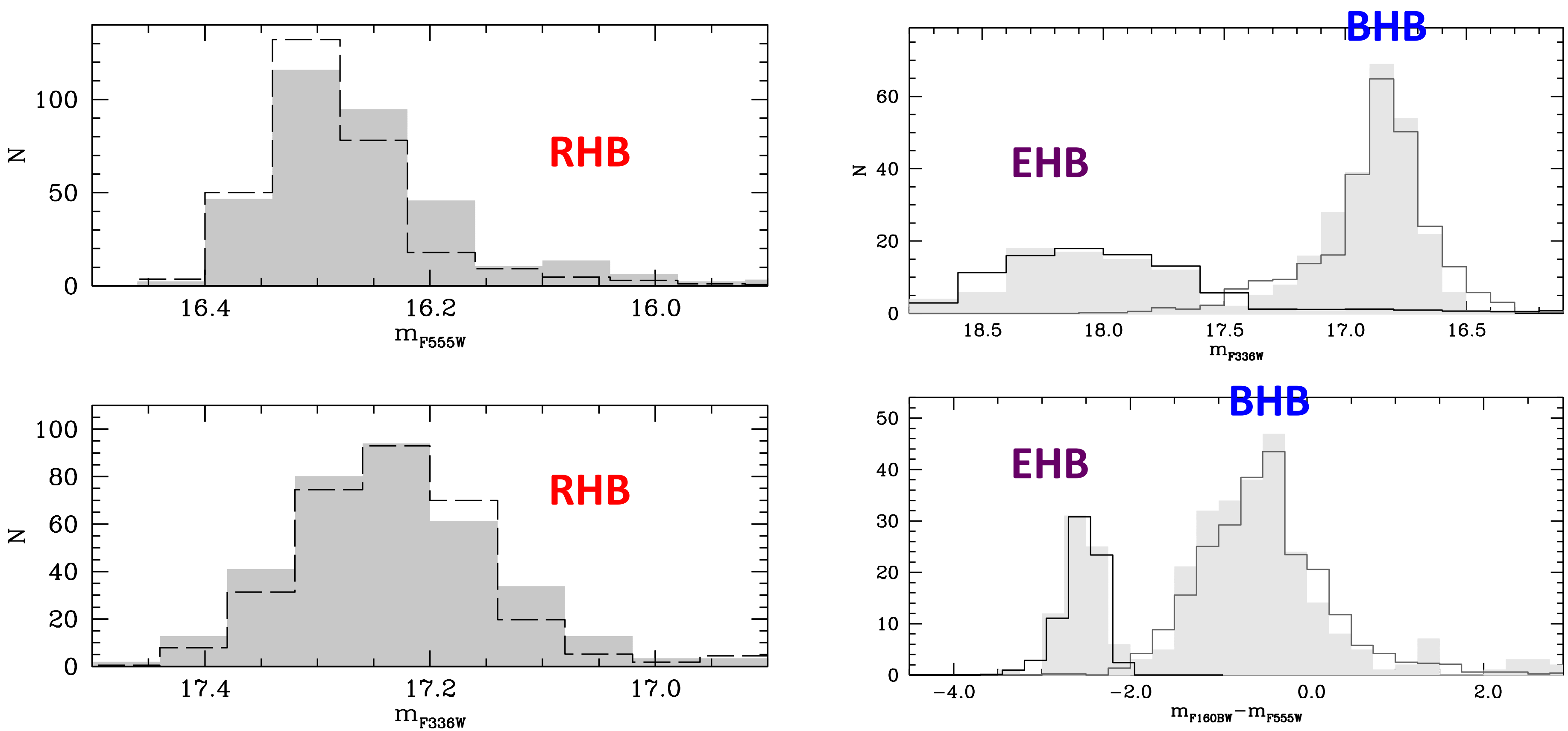
FAR-UV

2. Four sub-groups

Dalessandro et al. 2011



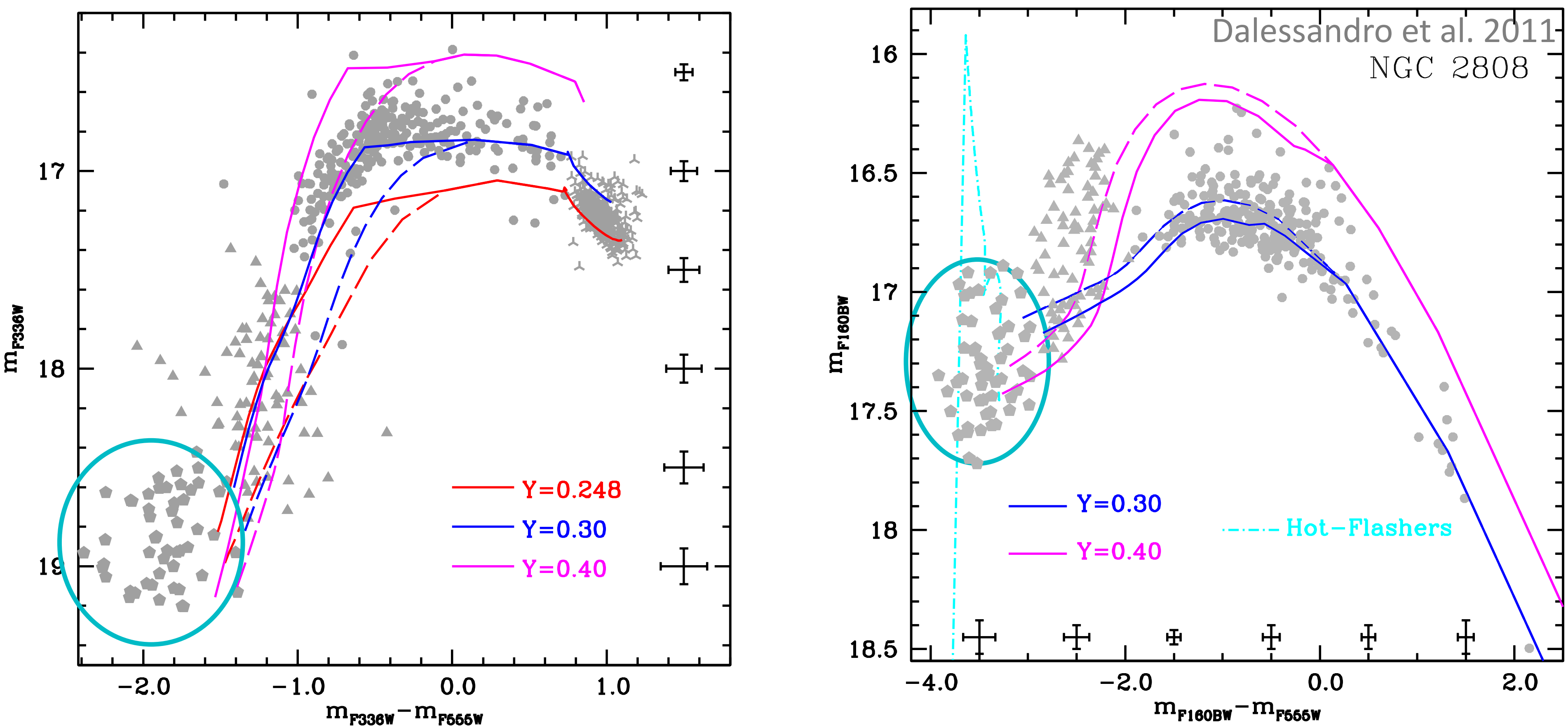
2. Comparing models with observations



POP	Y	M_{TO}	M_{HB}	DM	T_{eff}
RHB	0.248	0.84	0.69	0.15	5400
BHB	0.30	0.76	0.565	0.195	12 600
EHB	0.40	0.627	0.479	0.148	24 000

See also D'Antona et al. (2005, 2008)

2. The Horizontal Branch in UV: NGC 2808

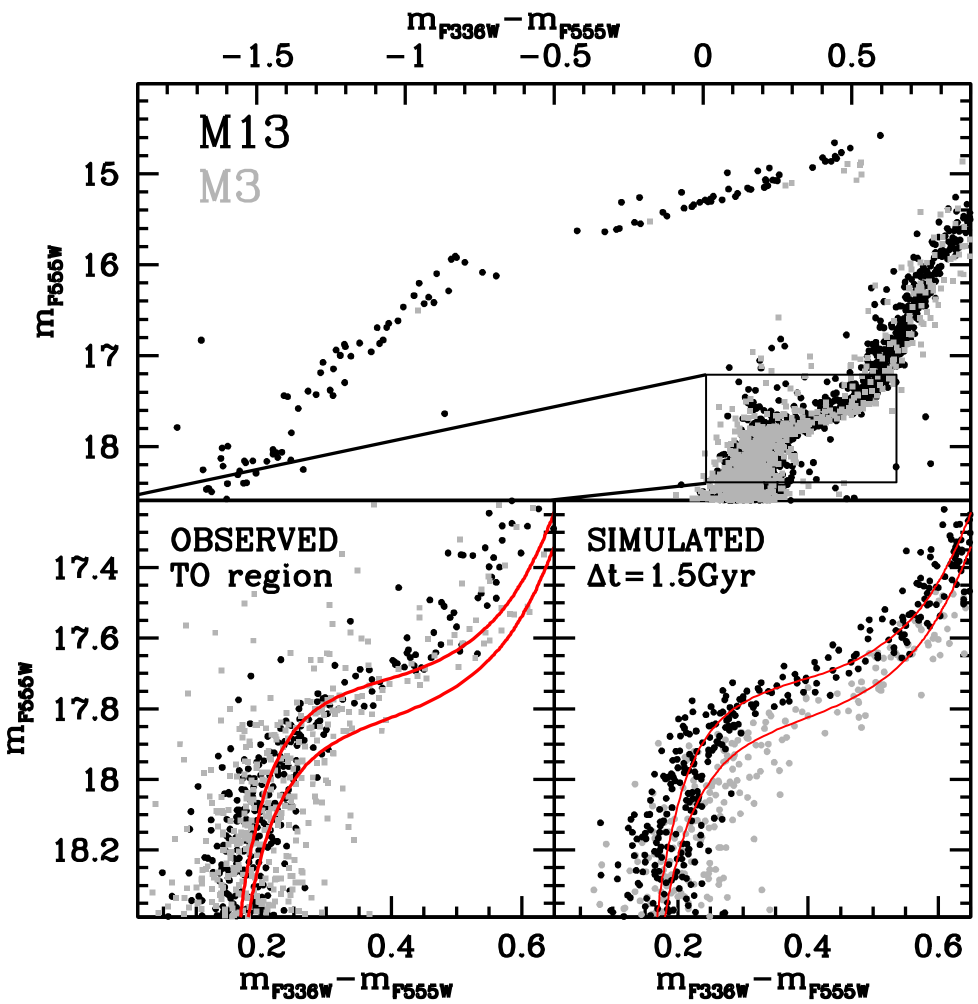


THE HB OF NGC2808 IS FULLY DESCRIBED BY USING 3 POPS WITH DIFFERENT He + HOT-FLASHERS

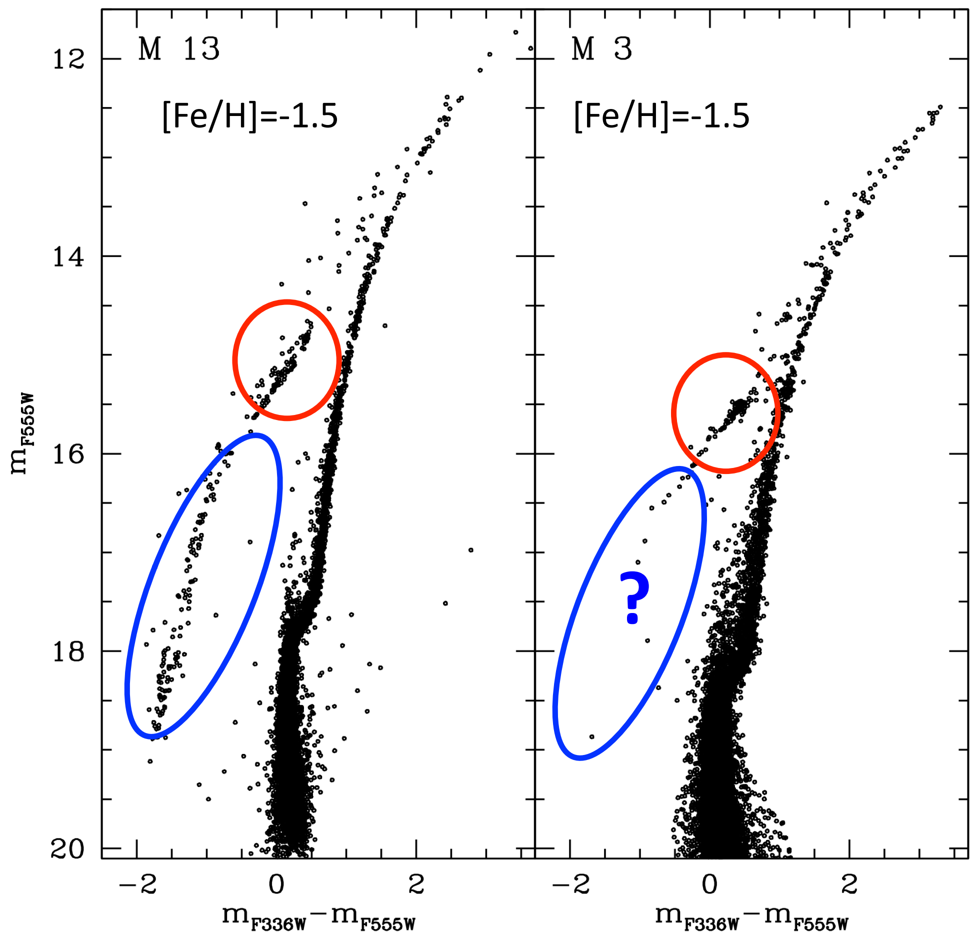
2. The Horizontal Branch in UV: M3 – M13

Dalessandro et al. 2013

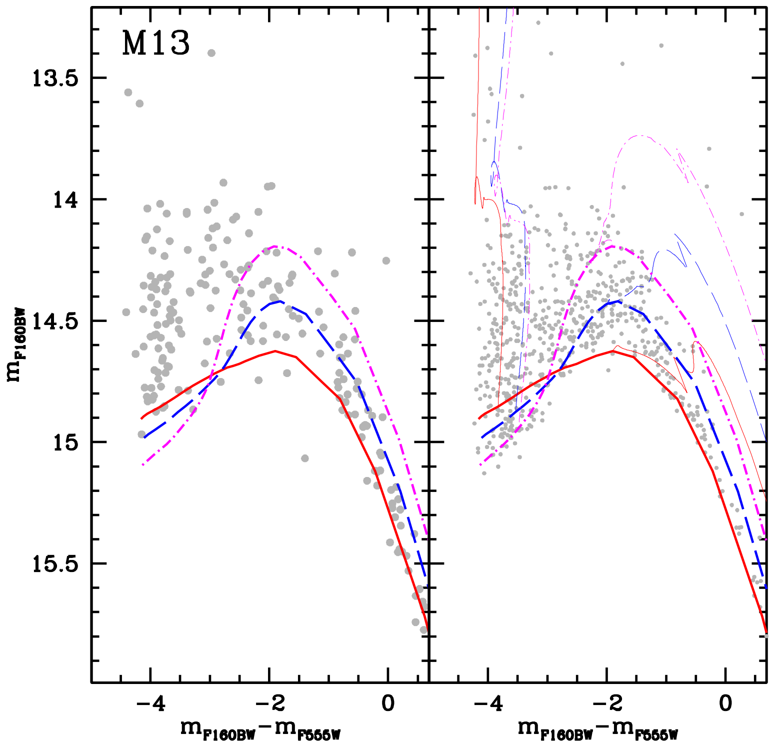
SAME METALLICITY, SAME AGE



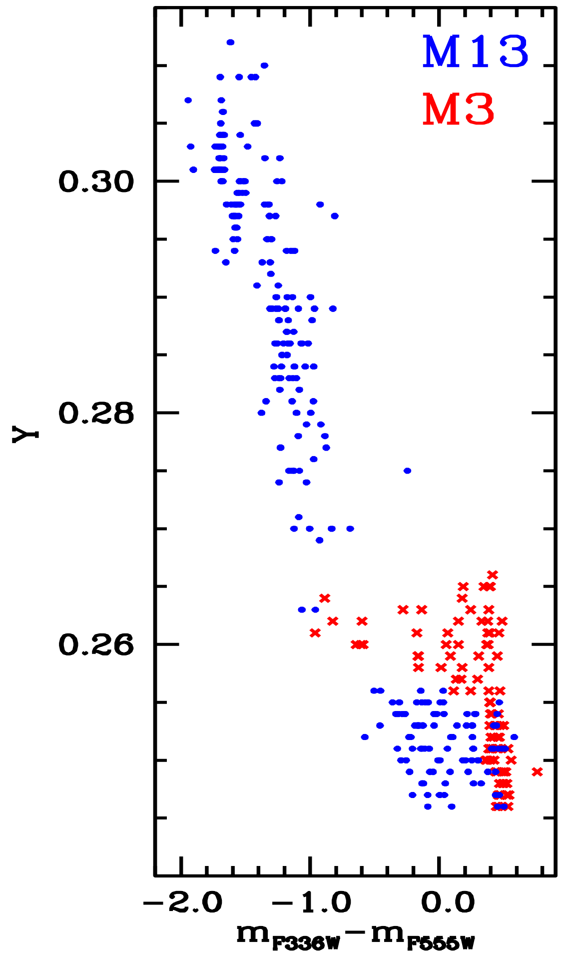
DIFFERENT HB MORPHOLOGIES



2. The Horizontal Branch in UV: M3 – M13



Dalessandro et al. 2013



HBs are matched only with different He distributions

See also Caloi & D' Antona (2005); D' Antona et al. (2008); Catelan et al. (2009)

3. An empirical Mass Loss Law

3. Mass loss in old RGB stars

Indirect evidence of ML:

- ✓ the HB morphology,
- ✓ the properties of RRLyrae,
- ✓ absence of AGB brighter than RGB tip
- ✓ Masses of WDs in GCs

NO empirical ML law calibrated on old giants

ML rates, timescales, driving mechanisms, dependence on stellar parameters & metallicity, still open issues

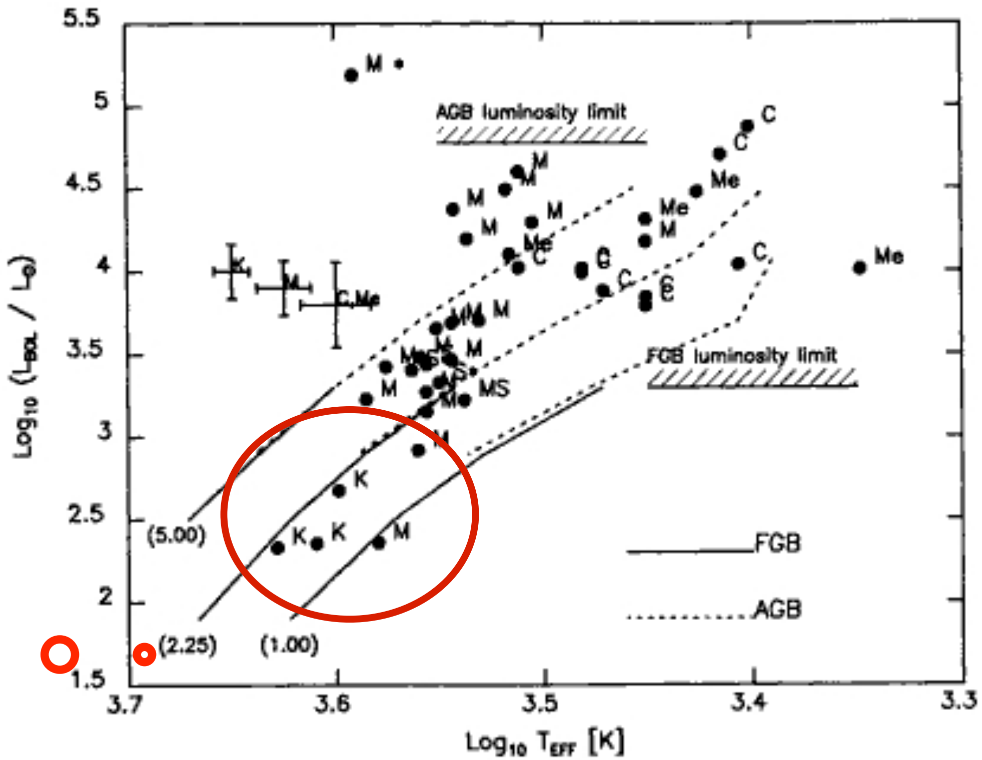
3. Mass loss in old RGB stars

Models incorporate ML using the analytical formula of Reimers (1975) calibrated on Pop I giants (see also Mullan 1978; Goldberg 1979; Kudge 1991):

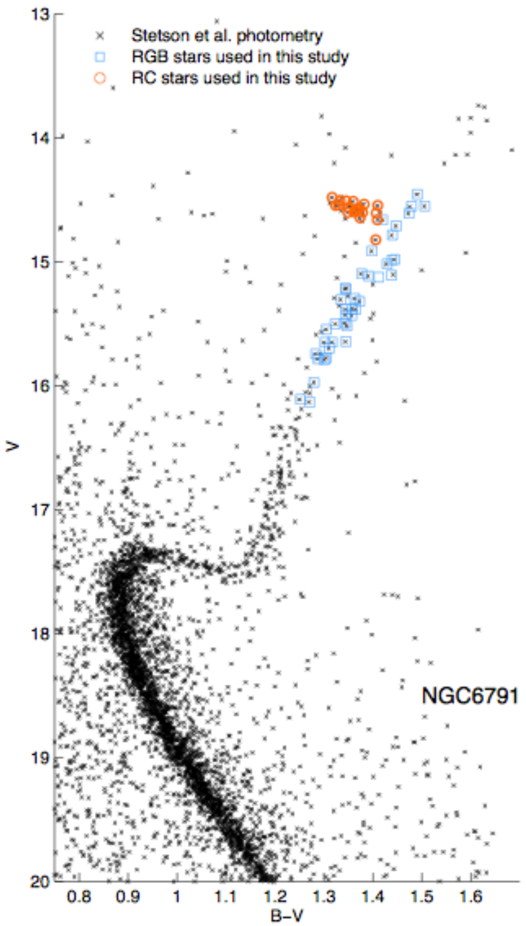
$$dM/dt = \eta \times 4\times10^{-13}\ L/gR\ [M_0/yr],\ \eta = 0.3$$

slightly revised by Catelan (2000) but still relies on a few giants, mainly AGB!

only 6 RGB!



3. Mass loss diagnostics

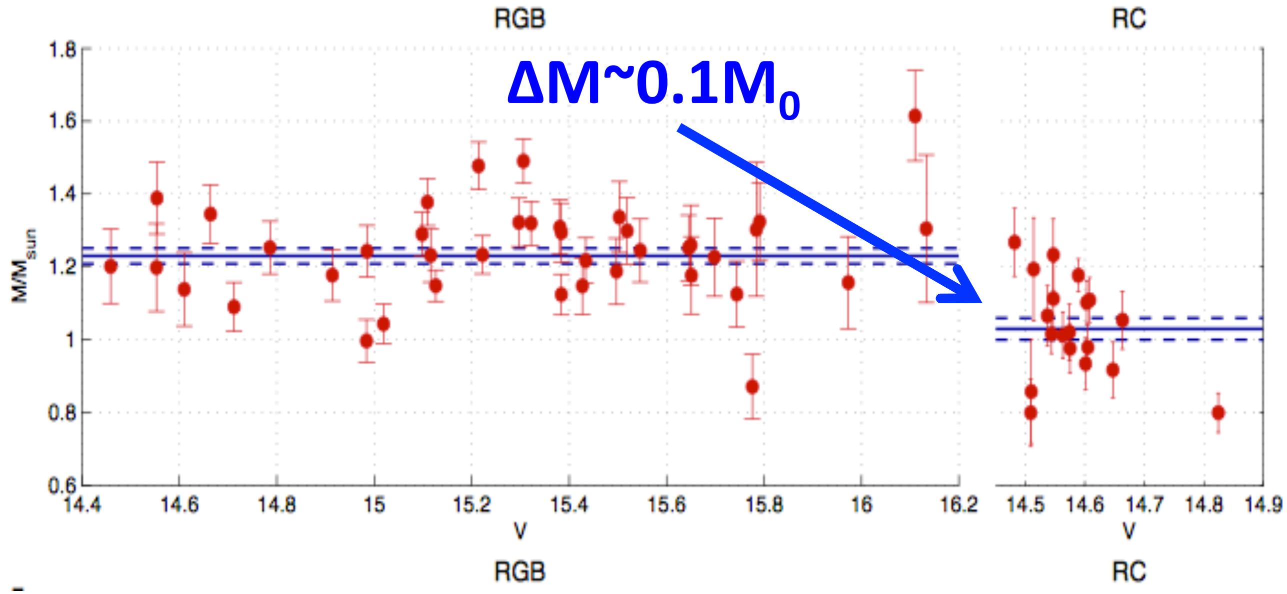


Asteroseismology

✓ Provides direct mass measurement

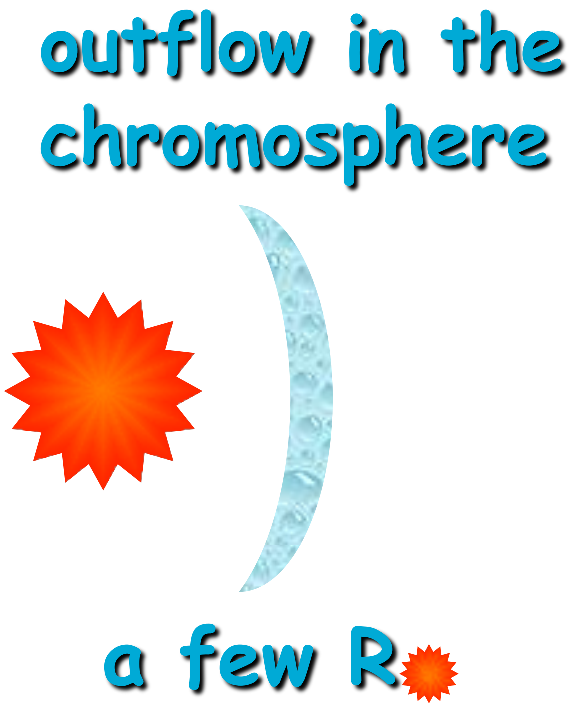
X No information about rates and lifetimes

Miglio et al. (2012)



3. Mass loss diagnostics

Mass loss diagnostics



chromospheric line analysis:

✓ effective to trace the region of wind formation & acceleration

However…

X difficult to convert wind line diagnostics into mass loss rates (both modeling & sampled region issues)

X bulk of mass loss better traced from the outer regions

X hard to take high res spectra of Pop II giants along the entire RGB

3. Mass loss diagnostics

- ✓ linear polarization
- ✓ Far-IR dust emission
- ✓ microwave CO emission …

X CS envelopes of Pop II giants have intrinsically low surface brightness

X Far IR & radio receivers have not sufficient spatial res & sensitivity to study Pop II CSE

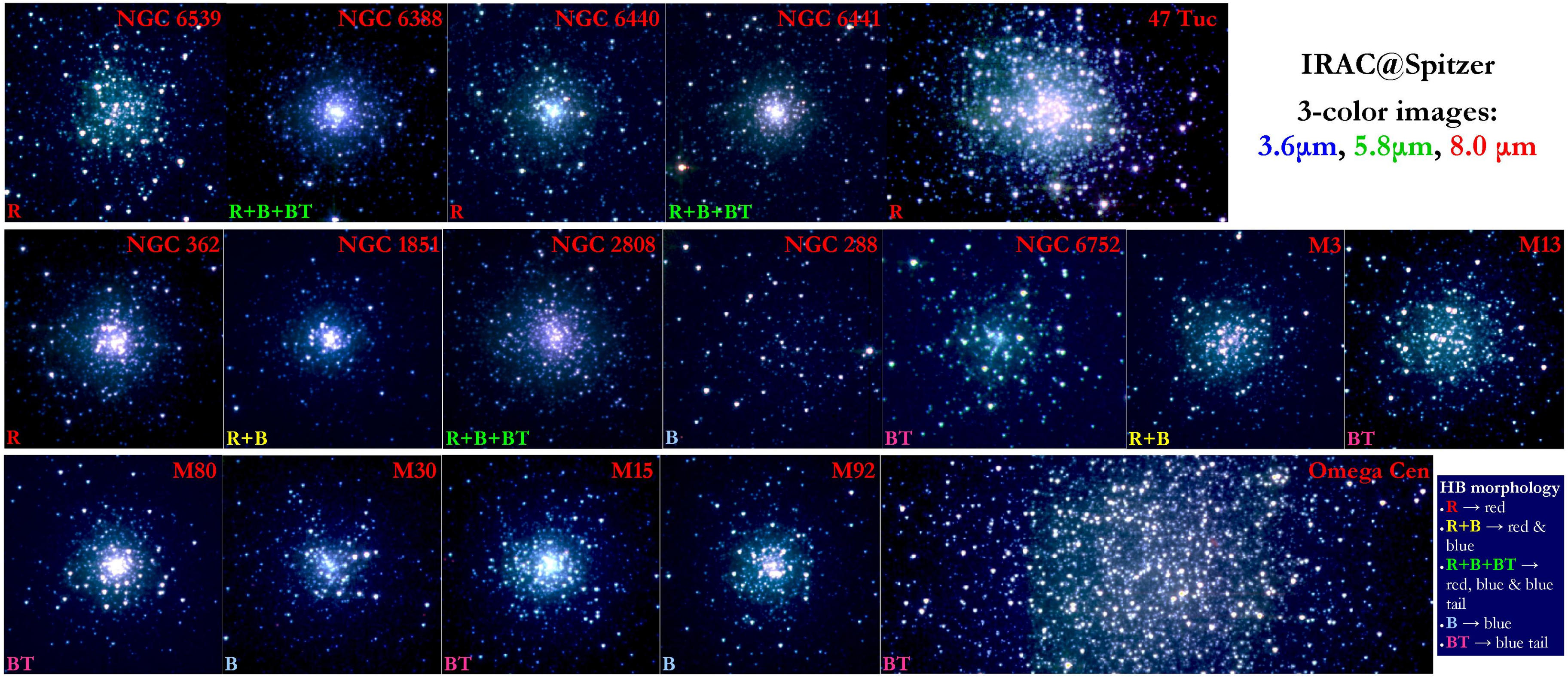
X Linear polarization hardly measurable

Mid-IR spectro-photometry is most effective to detect CSE of Pop II

Frogel & Elias 1988; Gillet et al. 1988; Origlia et al. 1996; Boyer et al. 2006; McDonald et al. 2007

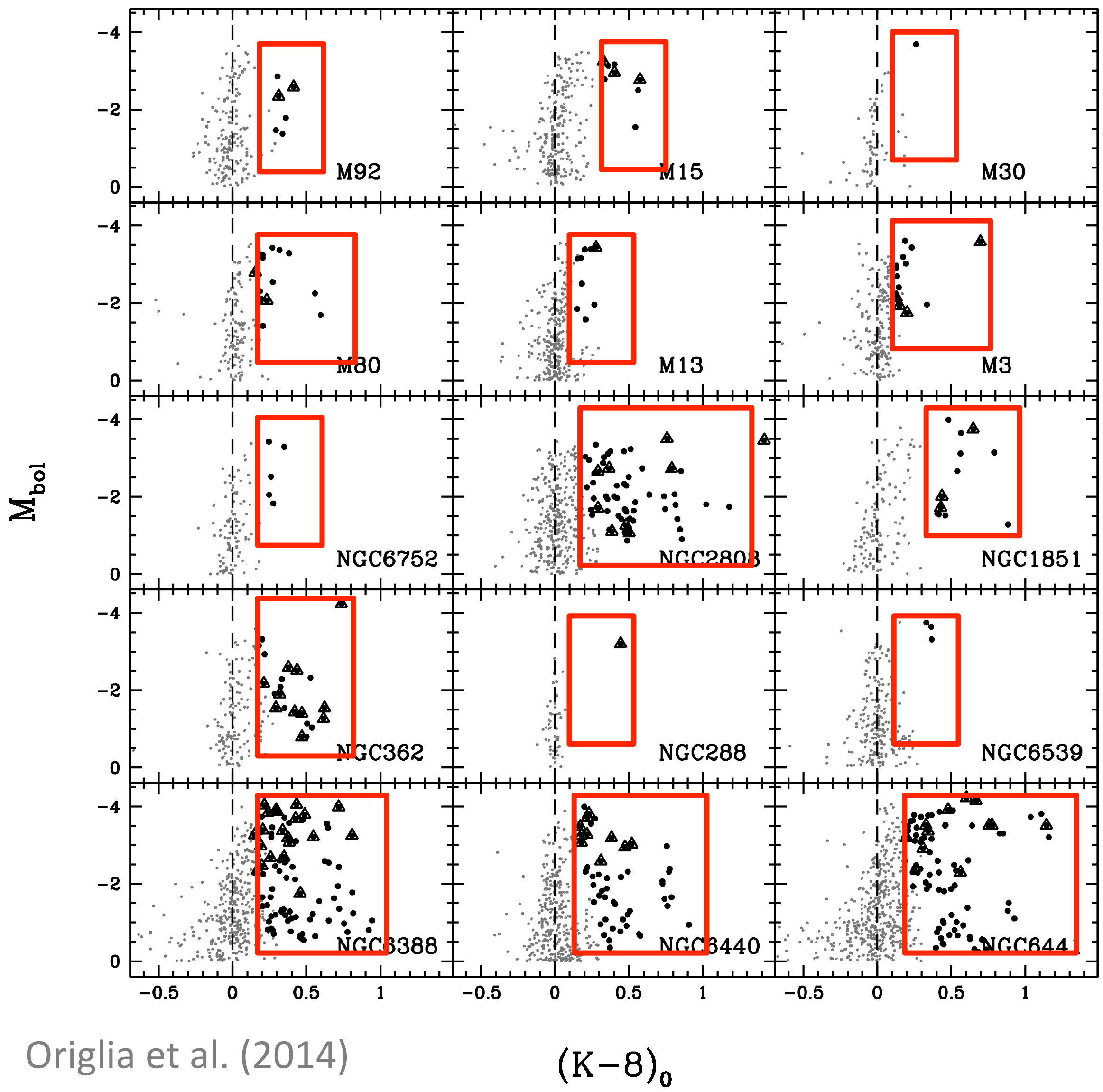
3. The IRAC@SPITZER survey

Exploring the Unknown Physics of Mass Loss in First Ascent Pop II Red giants



26hr - deep imaging (down to the ~HB) of 17 GGCs spanning the entire range of Z & HB morphologies

3. The IRAC@SPITZER survey: the CMDs



Origlia et al. (2014)

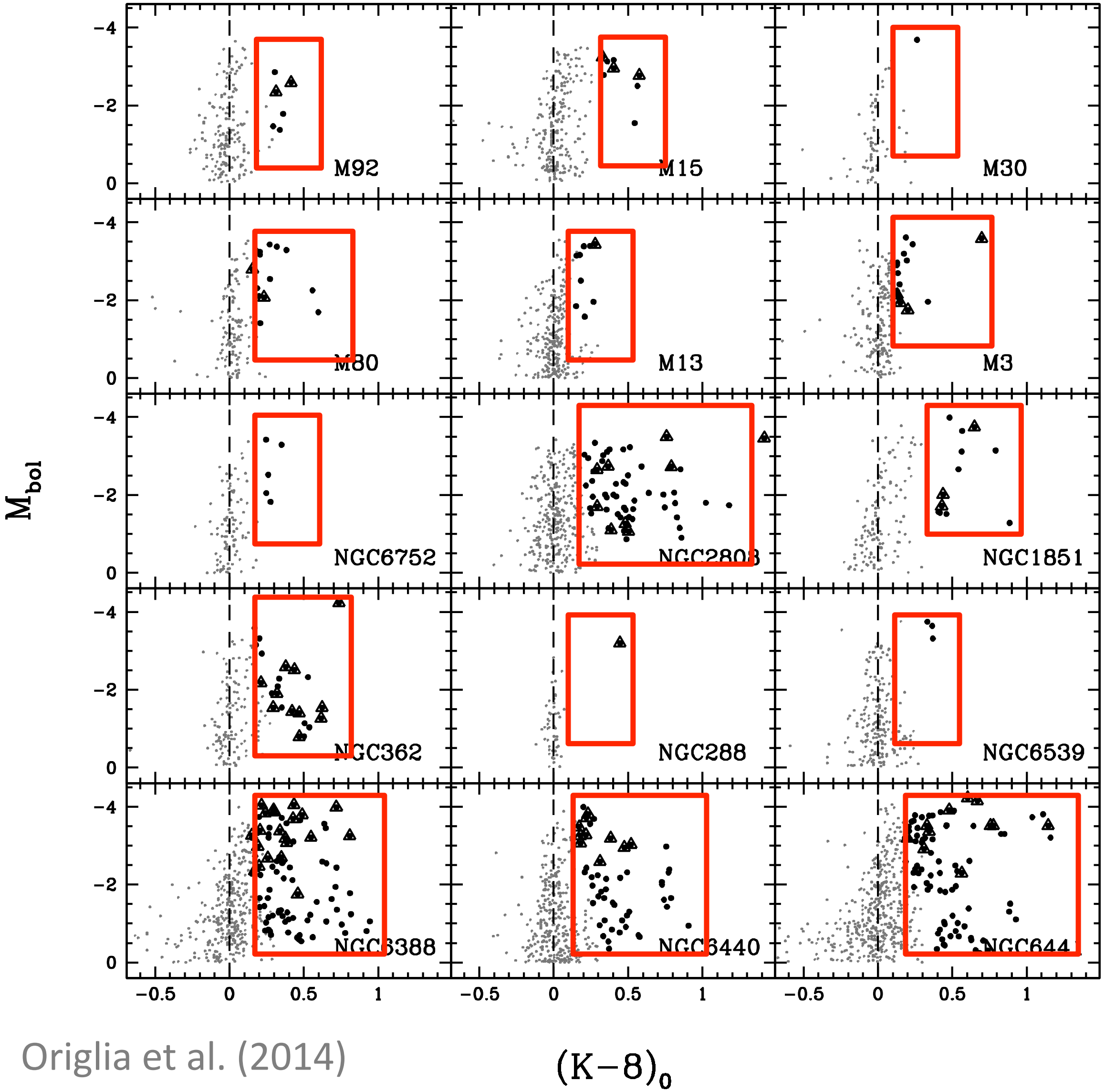
(K-8) IS THE BEST COLOR COMBINATION

✓Optical data to separate RGBs from AGBs
✓Blends and completeness
✓ Field stars contamination

Stars at > 3σ from the mean ridge line

DUST EXCESS

3. The duty cycle

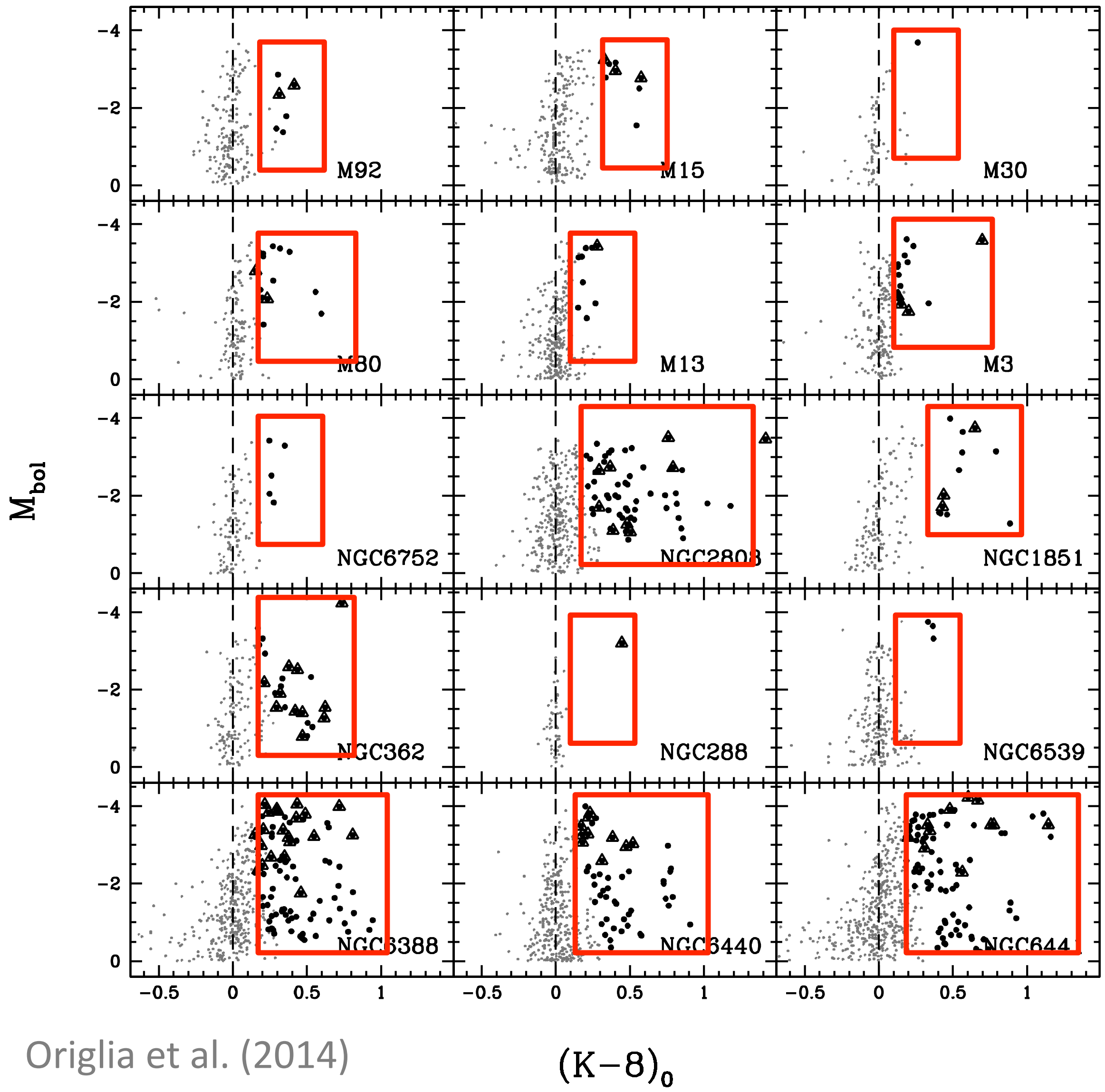


Origlia et al. (2014)

MASS LOSS IS EPISODIC and ACTIVE ONLY A FRACTION OF THE TIME

1. **DUTY CYCLE**
2. **MASS LOSS RATE**

3. The duty cycle



Origlia et al. (2014)

MASS LOSS IS EPISODIC and ACTIVE ONLY A FRACTION OF THE TIME

1. DUTY CYCLE

$$\Delta t^{ML} = \Delta t \times f$$

Δt is the evolutionary time (30 Myr)

$f = N_{dusty}/N_{tot}$

3. Mass loss rate

$$dM/dt = 4\pi r_{out}^2 \times \rho_{dust} \times v_{\exp} \times \delta$$

2. MASS LOSS RATE

INPUTS FOR MODELING THE CS DUST EMISSION (DUSTY code):
T_{eff} and (K-8)

ρ_{dust} is the dust density

$\delta = \rho_{gas}/\rho_{dust} \geq 1/Z$ → in GCs means that ~50% of α-elements can condense in dust

$v_{exp} \propto \delta^{-0.5}$ if dust & gas coupled (e.g Morris et al. 1996)

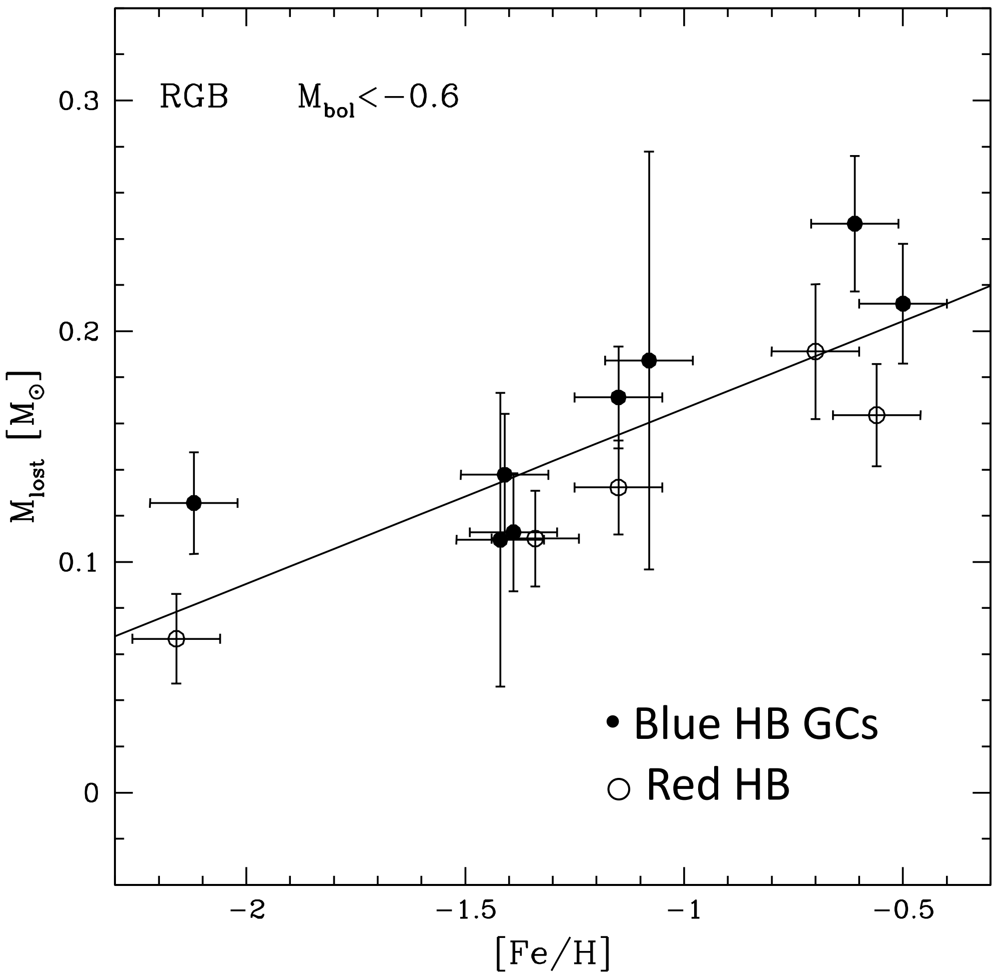
in 47 Tuc: δ=200 v_{exp}=10 km/s

3. The first empirical mass loss law

$$\Delta M = \sum_i (dM/dt_i \times \Delta t_i^{ML})$$

MASS LOSS RATE **DUTY CYCLE**

3. The first empirical mass loss law



Origlia et al. (2014) – Dalessandro et al. (2011; 2013)

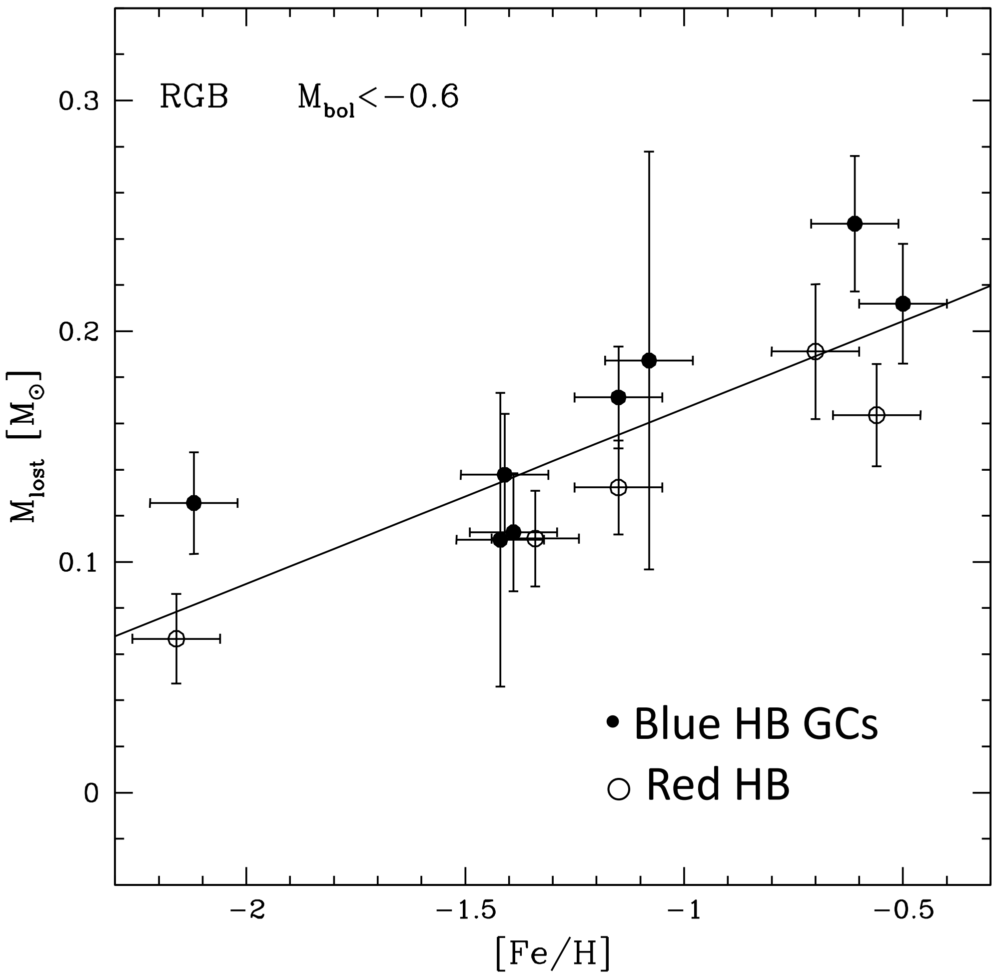
ML rate

ML moderately increases for increasing metallicity

$$ML^{RGB} = 0.08 \times [Fe/H] + 0.24\, M_{\oplus}$$

AT FIXED METALLICITY BLUE HB GCs TEND TO LOOSE MORE MASS THAN GCs WITH RED HBs

3. The first empirical mass loss law



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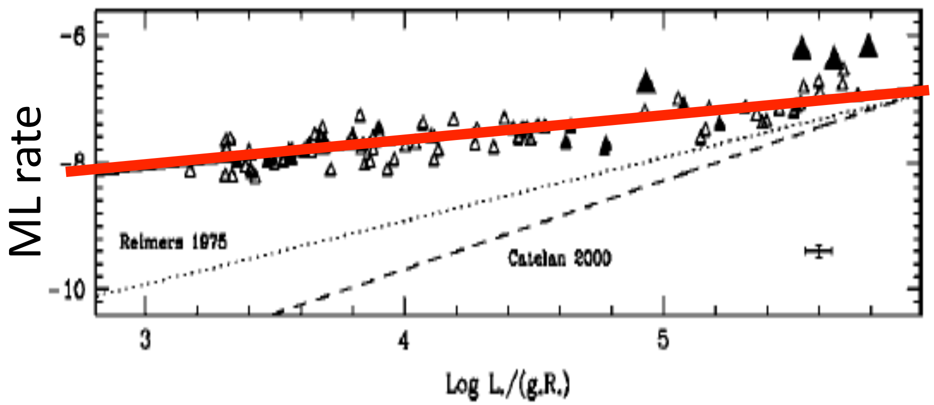
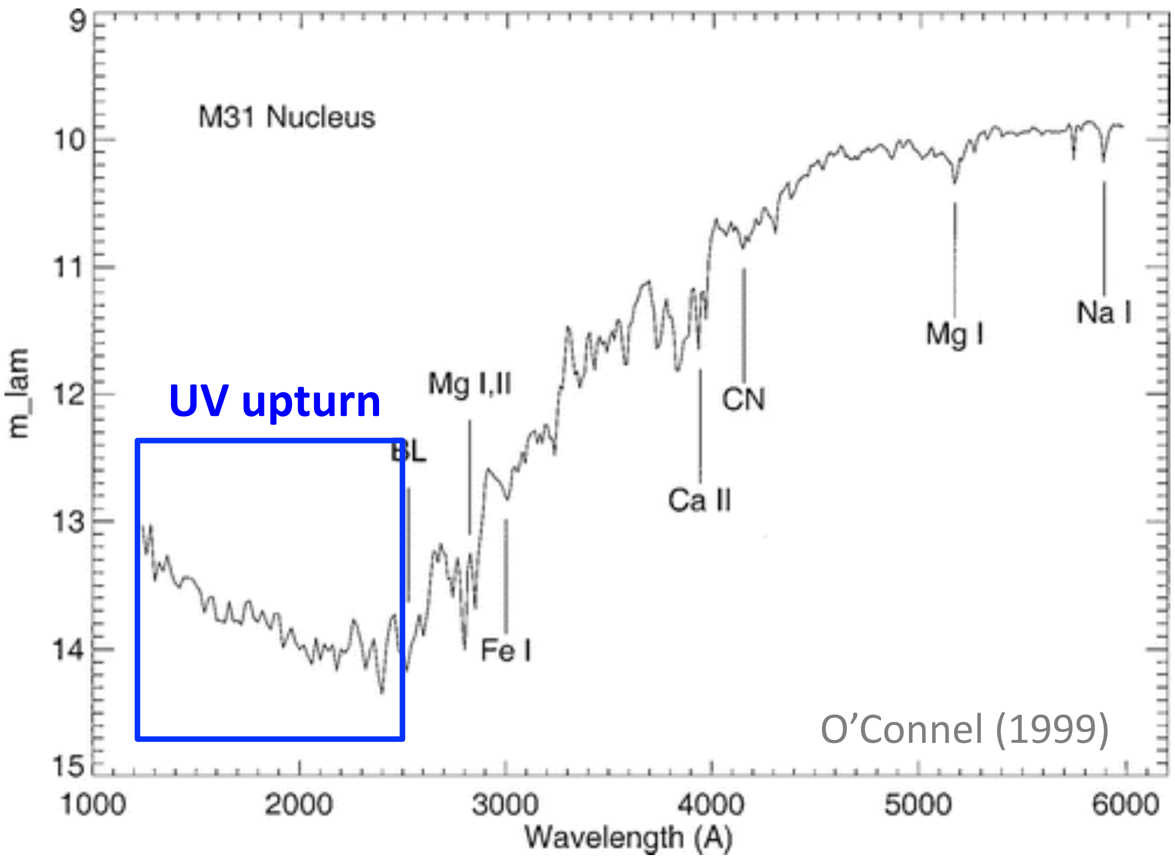


Origlia et al. (2014) – Dalessandro et al. (2011; 2013)

4. The HB morphology in extra-galactic GCs

4. Integrated UV properties

Understanding the origin and the frequency of hot stars is not simply a problem of understanding the evolution of old, low mass stars.
It has important implication on the interpretation spectra of galaxies.



Hot stars have been suggested to be responsible of the UV upturn in the spectrum of elliptical galaxies and bulges (Greggio & Renzini 1990)

4. Integrated UV properties

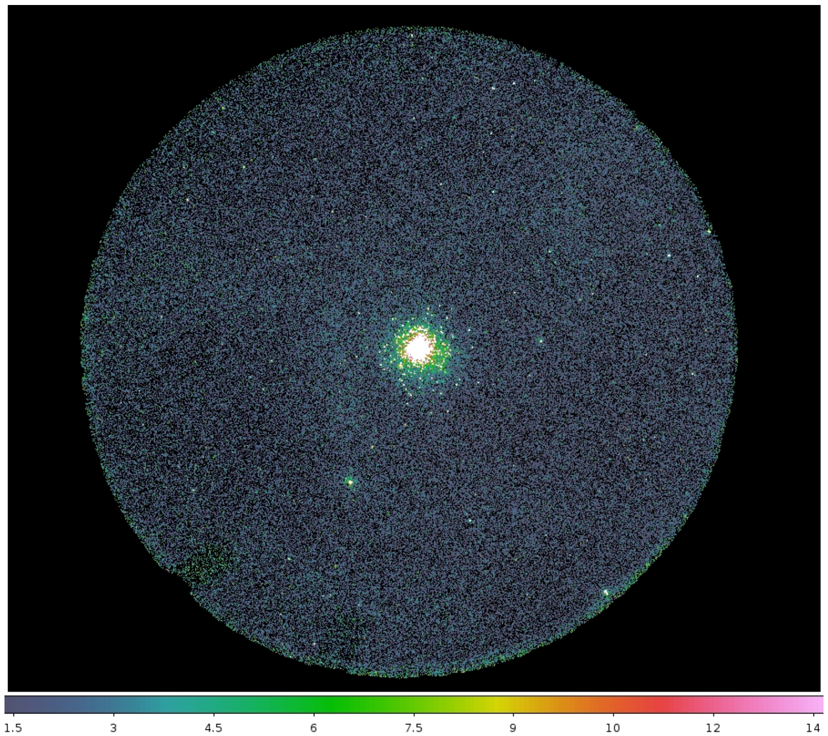
Detailed knowledge of the underlying stellar population

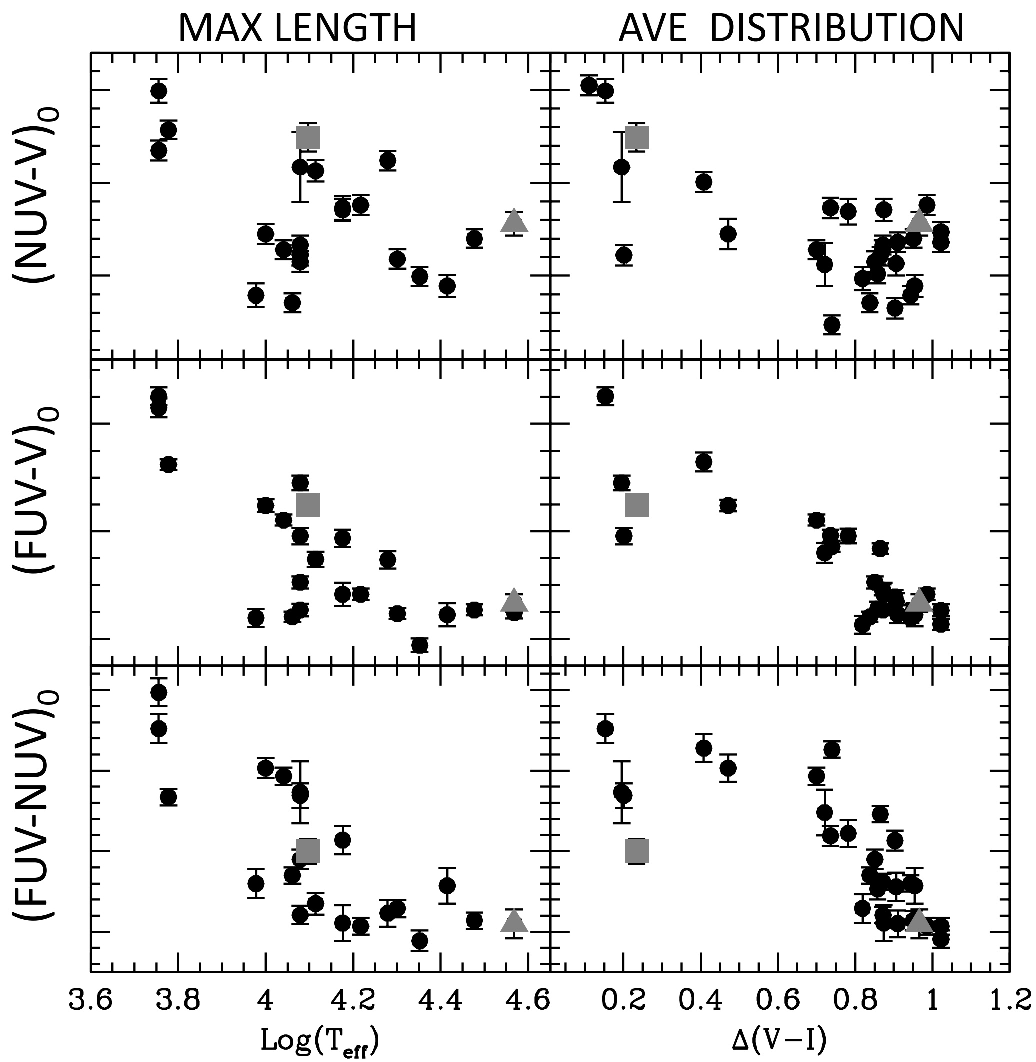
→

Integrated properties

4. Integrated UV colors with GALEX

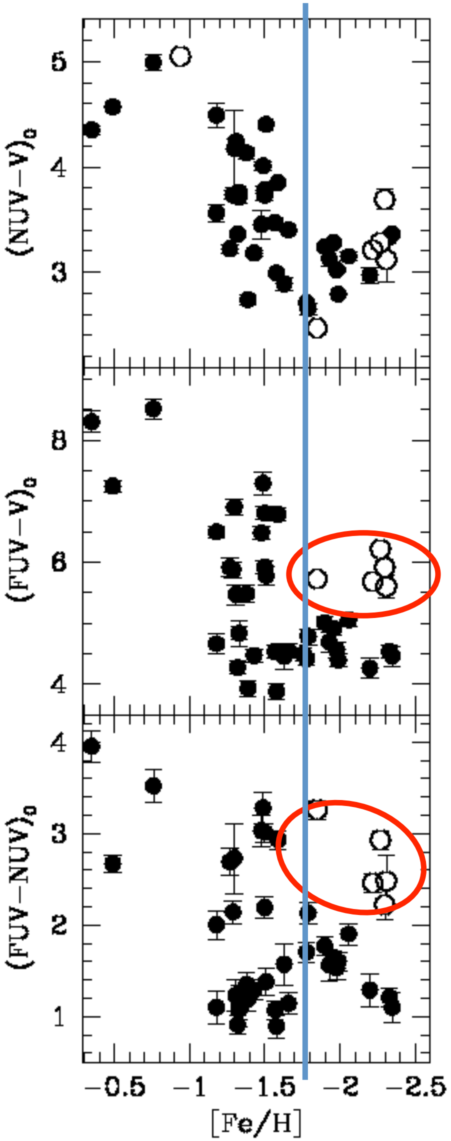
The largest homogeneous dataset of UV GGCs ever collected



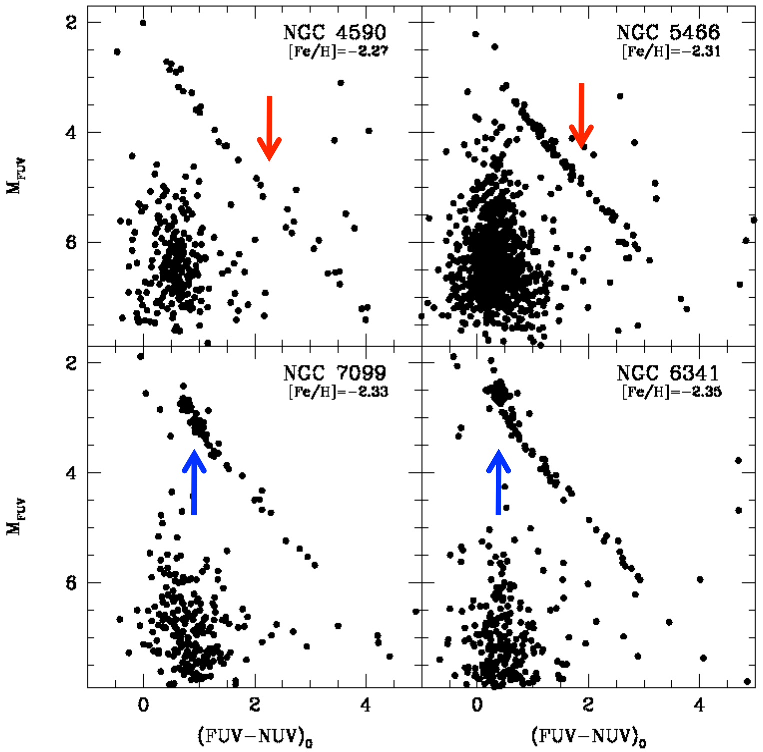


Dalessandro et al. (2012), Schiavon et al. (2012)

4. The Sagittarius clusters



Dalessandro et al. (2012), Schiavon et al. (2012)

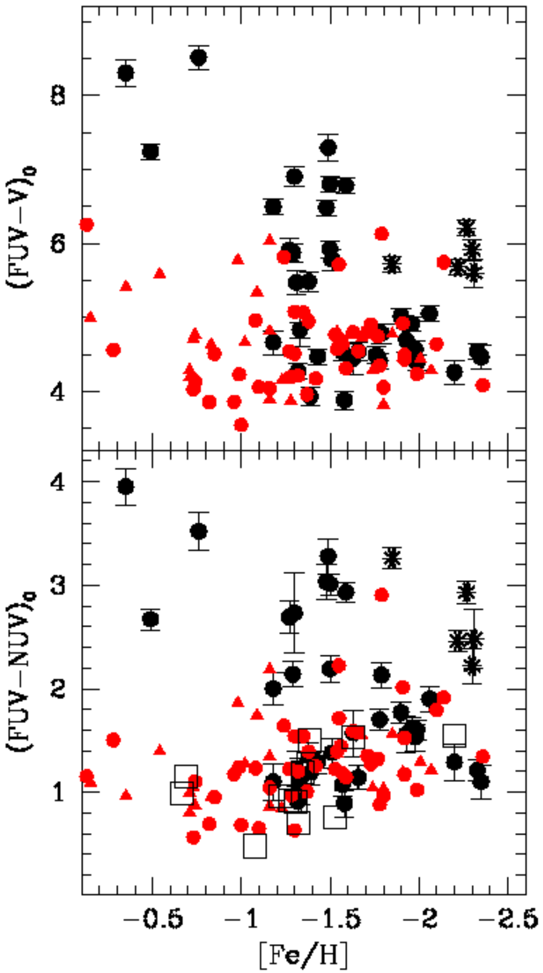


NGC4590, NGC5053, NGC5466, Arp2, Terzan8 and Palomar 12 are suggested to be connected with the Sagittarius Stream (Dinescu et al 1999, Palma et al. 2002, Bellazzini et al. 2003, Lee & Majewski 2010)

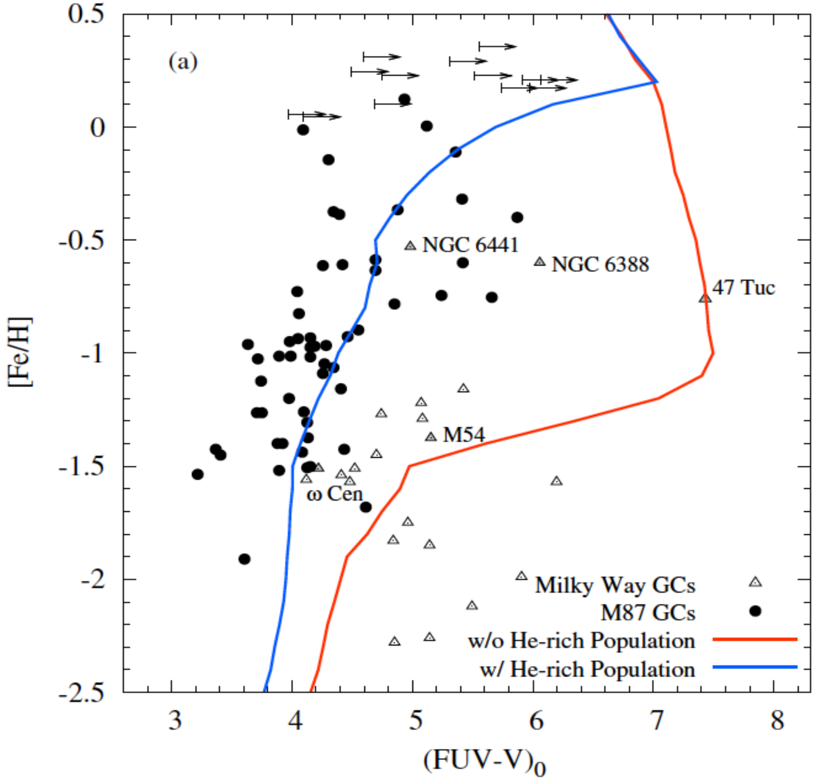
4. M31 and M87 GCs

Dalessandro et al. (2012)

On average M31 and MW GCs have the same UV colors

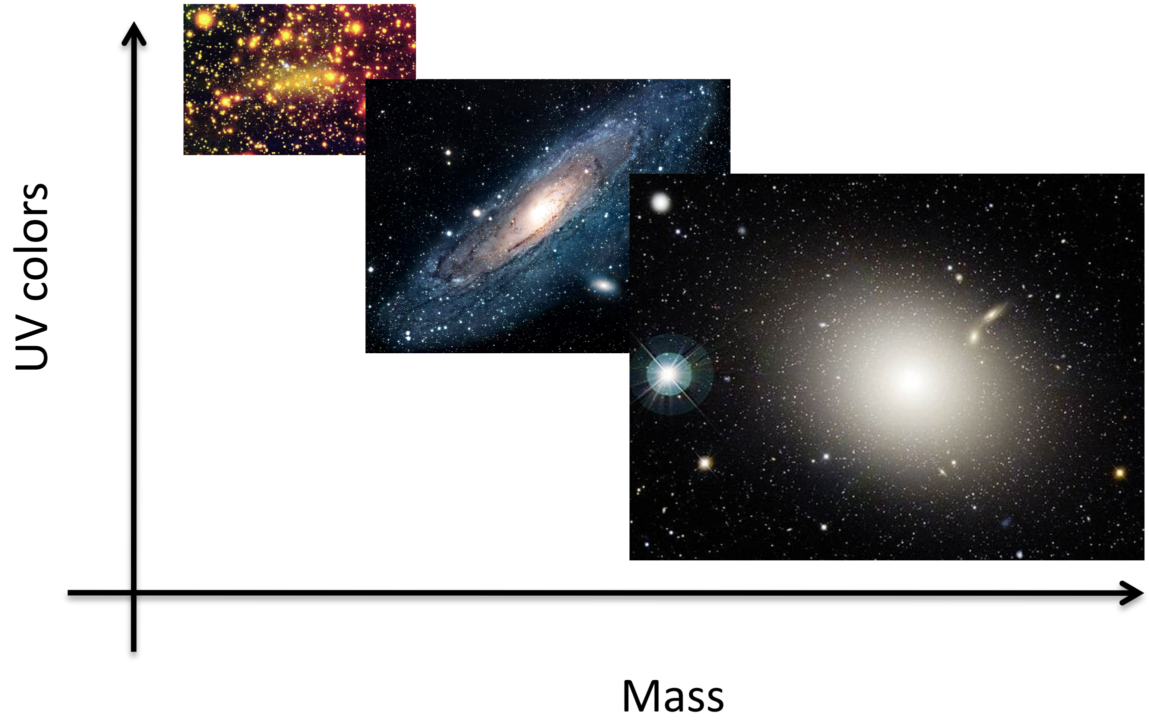


On average M87 GCs are bluer than GGCs



4. Mass really matters

Dalessandro et al. (2012)



UV colors of GC systems get bluer as the mass of the host galaxy gets bigger

He is driving the HB morphology in extra-galactic GCs

5. Summary

- Mass loss and He are key for our understanding of the HB morphology

- We have shown that He plays a crucial role in GGCs. Its modeling requires assumptions about mass loss

- We derived the first empirical mass loss law for Pop II giants

- We observe a general correlation between UV colors of GCs and mass of the host galaxy

- This would suggest that He are efficiently shaping the HB morphology also outside the Galaxy

Thank you!

Visit our web-site: www.cosmic-lab.eu