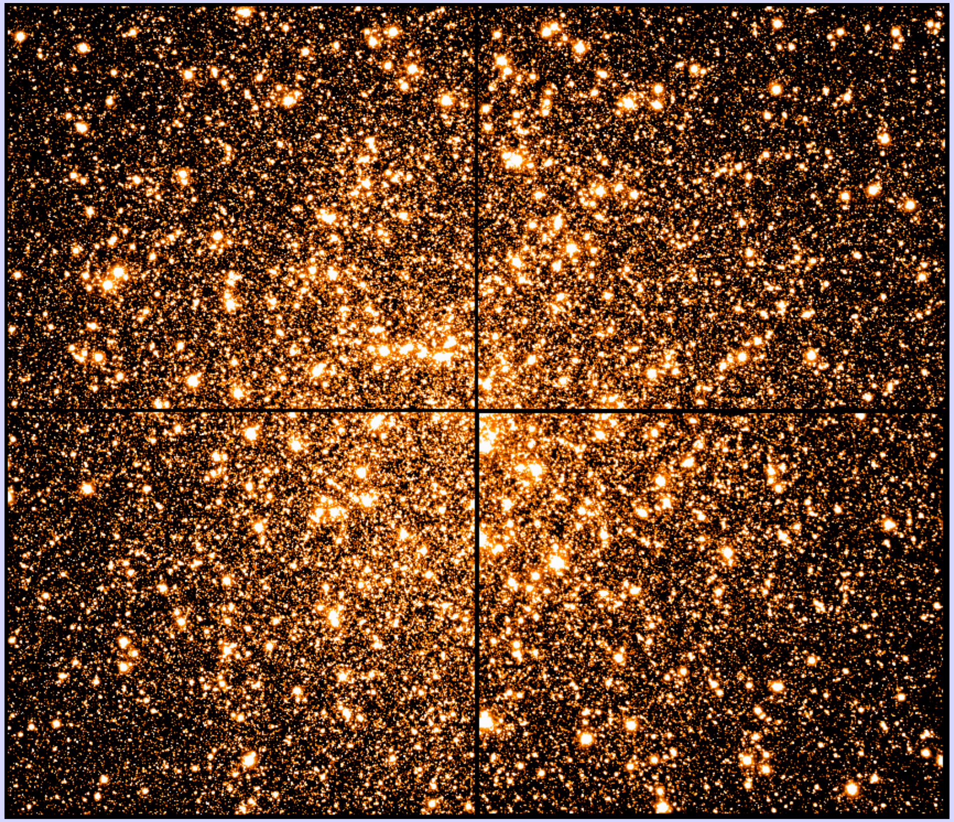
Omega Centauri: the possible link between GCs & dSphs

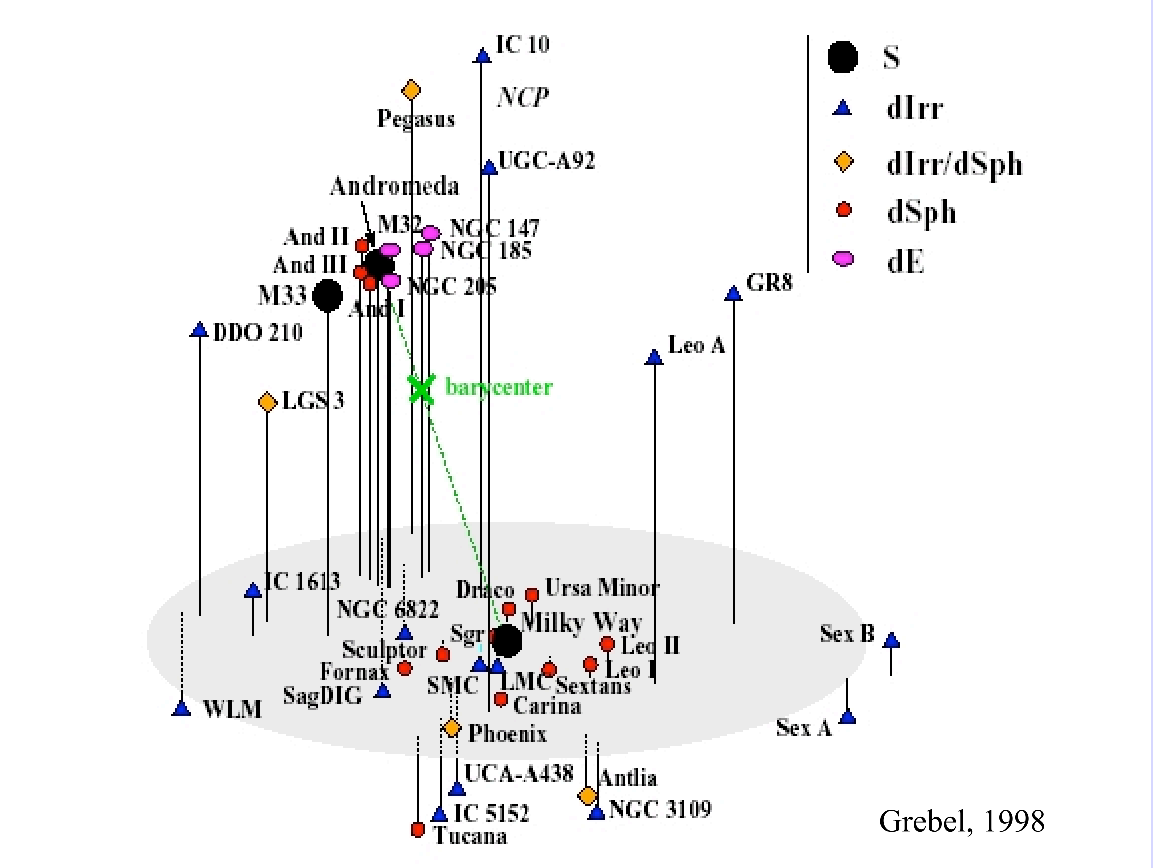


G. Bono – INAF / Rome Astron. Obs. & ESO/Garching

OVERVIEW

- Brief overview on dSphs & GCs
- _ Centauri intrinsic properties
- Star counts in _ Cen and their impact on canonical and He-mixed populations
- Hints on the final fate of low-mass stars
- Conclusions & Future developments

The Local Group



Grebel, 1998

two dominant spirals

+

~38 nearby dwarfs

- representative of all low luminosity galaxies
- morphology
- star-by-star study
- star formation history
- chemical enrichment
- gas content

Dwarf Spheroidals (dSphs)

- low mass → $\sim 10^7 M_o$
- low surface brightness → ~ 23 mag/arcsec^2
- low central density → $0.1 L_o/pc^3$
- high M/L → $5 \div 330\ M_o/L_o$
- low internal velocity dispersion → <10 km/s
- absence of dust and gas

ideal building blocks in _CDM models

But…

- complex star formation histories with *recent* episodes (< 1Gyr)

- missing satellites

- *tidal* interactions with the Galaxy ?

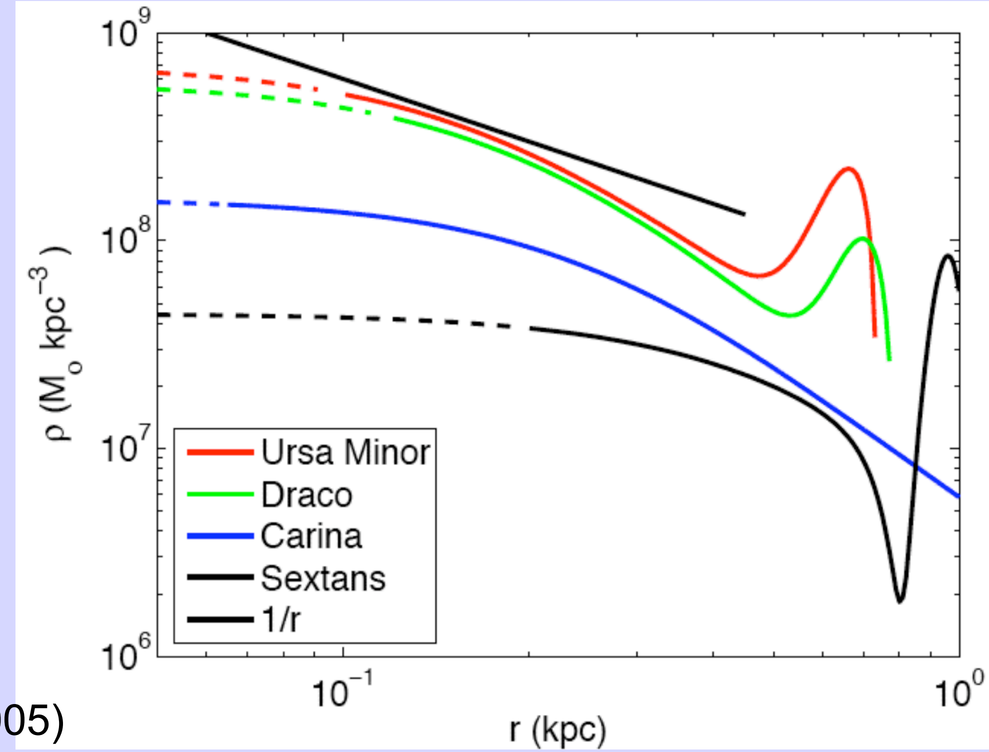
Are dSphs Dark Matter dominated?

Problems for ΛCDM cosmology

(σ,L) similar to GCs but R = 20 R_{GC} → M/L ~ 20

→ but DM-profiles difficult to re-concile with theory

The measured light and line-of-sight velocity dispersion profiles of most dSphs can only be modelled with a cored DM density profile, but most CDM simulations predict a cuspy profile.



Gilmore et al. (2006)

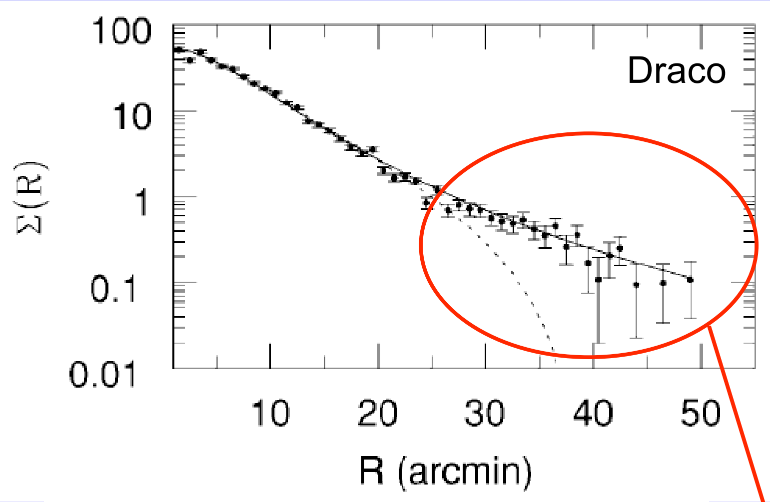
Possible solution:

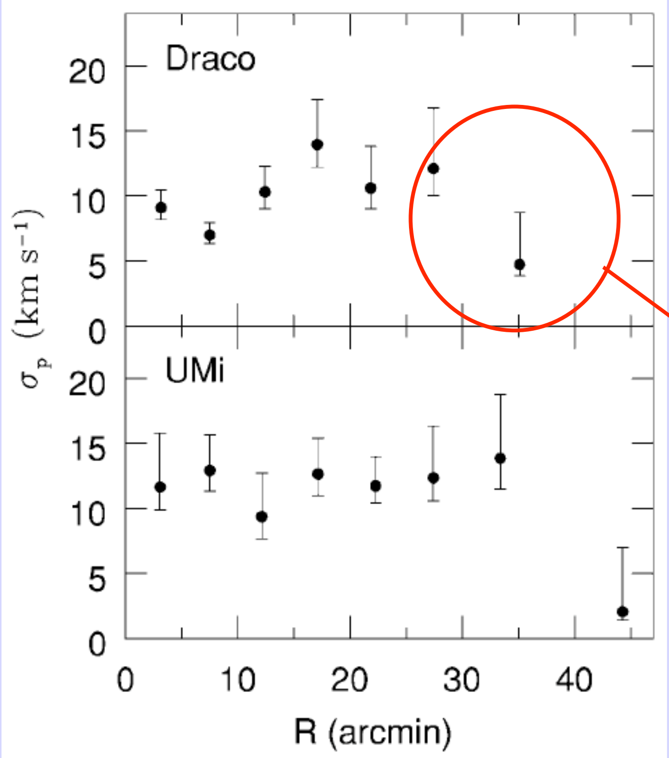
radiative pressure at z>10 (Ricotti & Wilkinson 2004)

periods of mass-loss and re-accretion of gas (Read & Gilmore 2005)

stellar feedback (Mashchenko et al. 2006)

Surface brightness and velocity dispersion profile





M/L values of Local Group dSphs

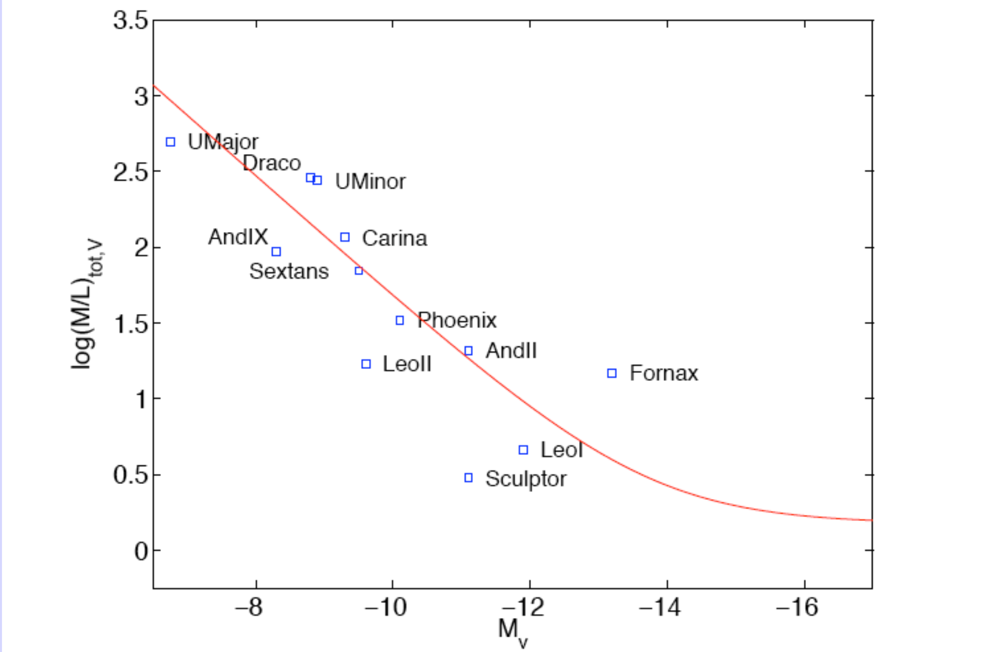


FIG. 5: Mass to light ratios *vs* galaxy absolute V magnitude for some Local Group dSph galaxies. The solid curve shows the relation expected if all the dSph galaxies contain about 4×10^7 solar masses of dark matter interior to their stellar distributions.

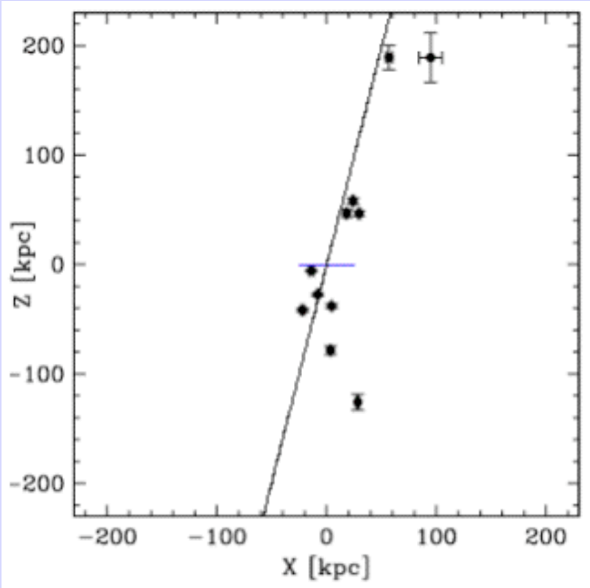
Wilkinson et al. (2004)

Outer part of Draco filled with a dynamically colder stellar population, which could be caused by an external tidal field??

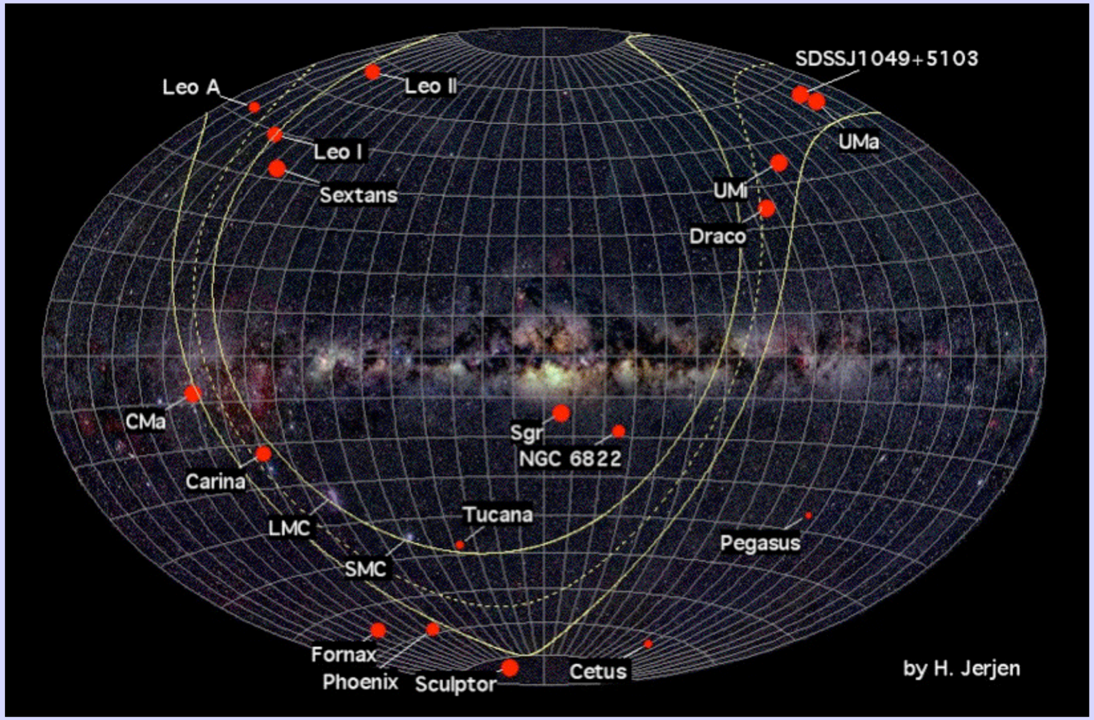
Problems for ΛCDM cosmology

disk-like spatial distribution of dSphs (polar plane)

→ incompatible with MW DM halo shape



Kroupa, Theis & Boily (2005)



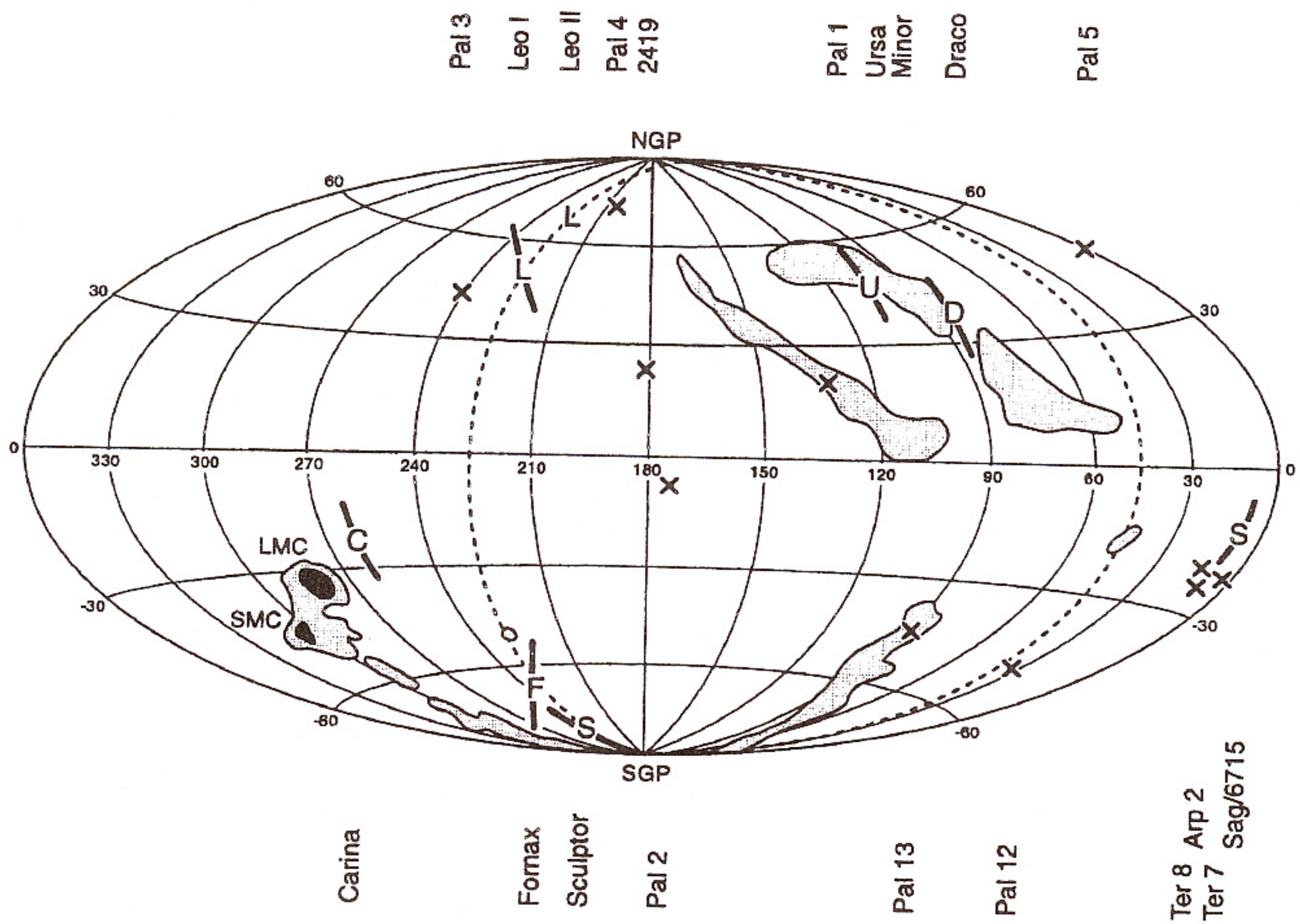
Possible solution:

Some CDM simulations seem to explain the anisotropic spatial distribution (Zentner et al. 2005, ApJ; Libeskind et al. 2005, MNRAS; …)

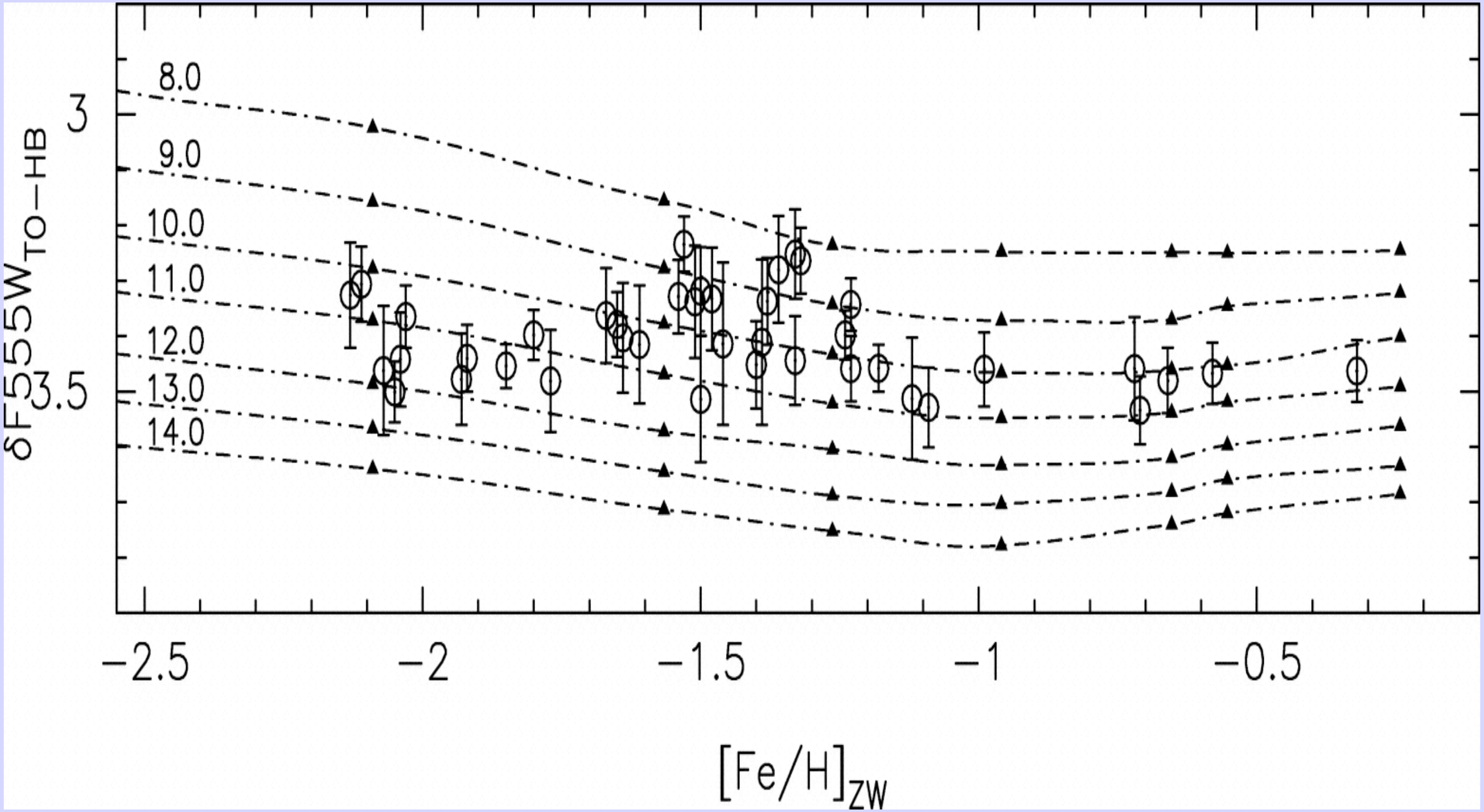
Still many inconsistencies + low statistics!

An alternative explanation for the LG dSphs

The “Disk of Satellites” might suggest a causal



Galactic Globular Cluster System



De Angeli et al. 2005, WFPC2@HST

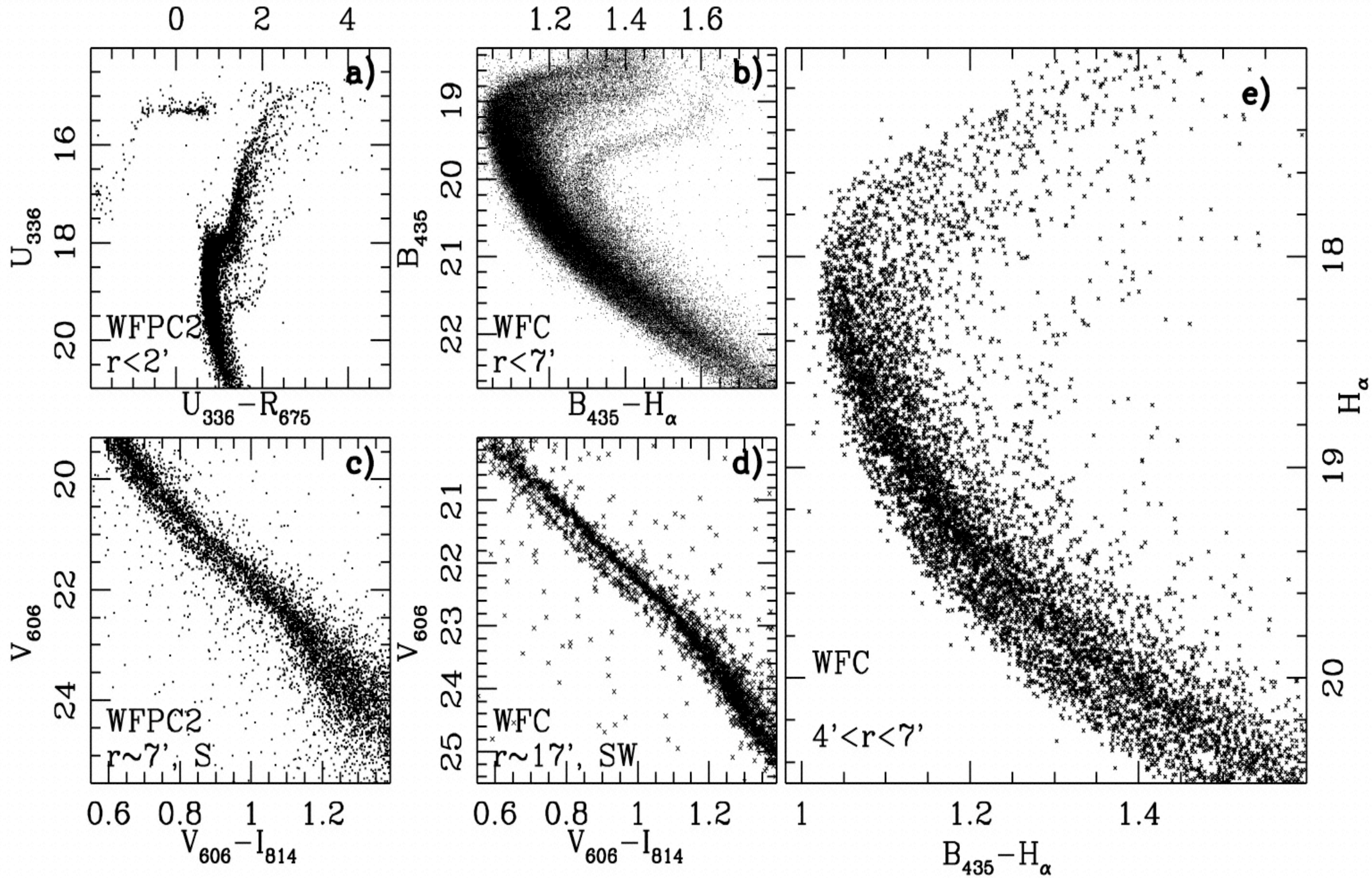
- **Simple Stellar population → TO mass ≈ 0.8 Mo**
- **Coeval, within current uncertainties, 1-2 Gyr**
- **No spread in chemical abundances**

- **Low M/L ratio ≈ 2**
- **High internal velocity dispersion > 10 km/sec**
- **High central densities log _ ≈ 5-6 (not only PCC)**
- **Total mass 10^6 – 10^7 Mo**
- **No dust no Gas**

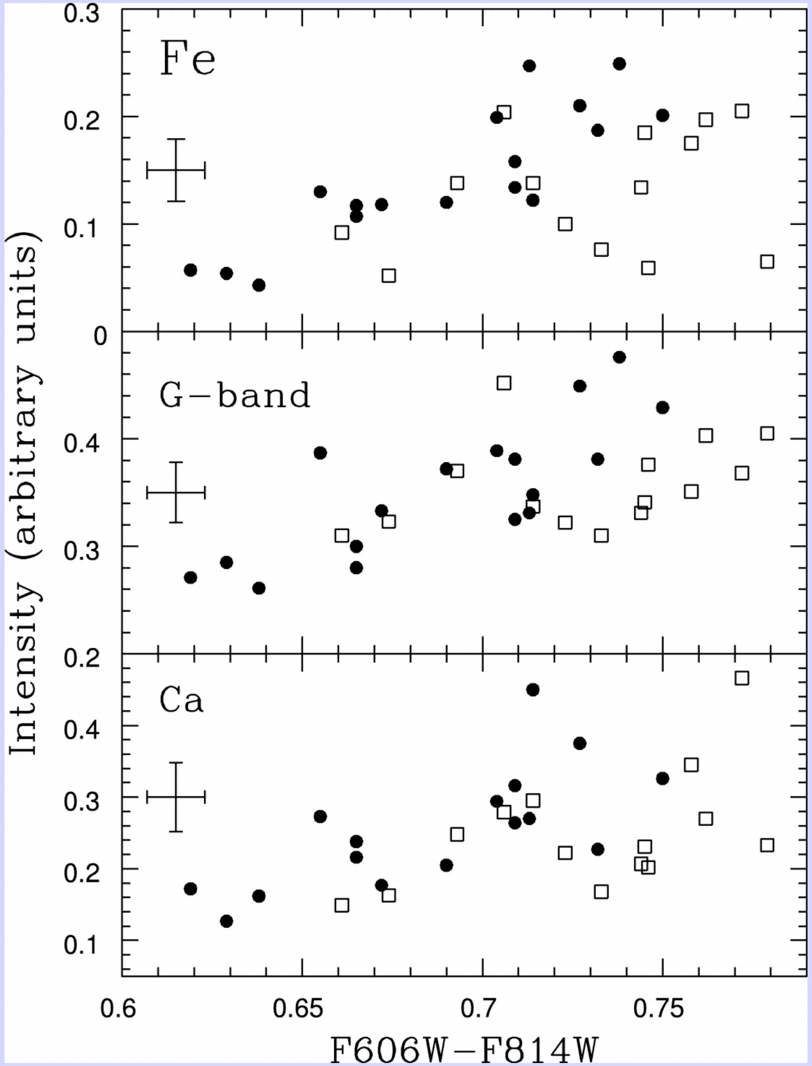
Omega Centauri

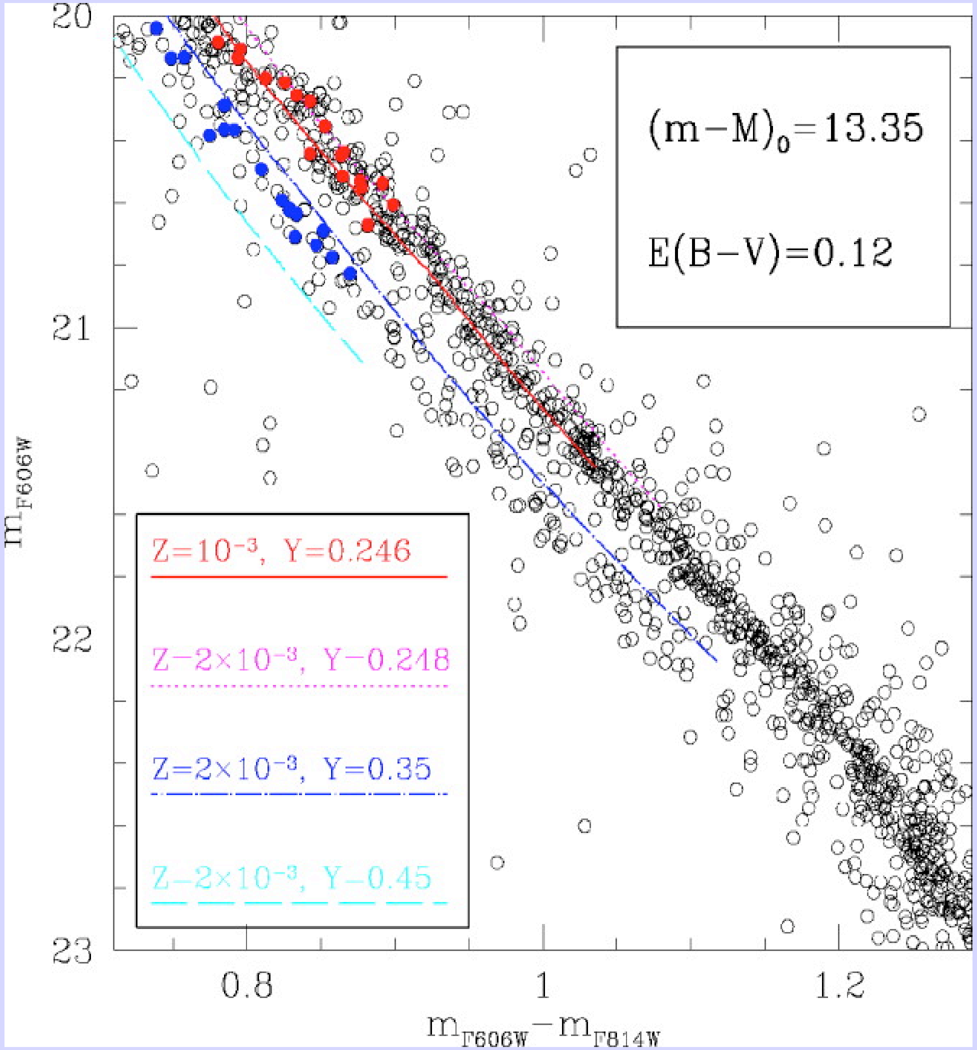
- **The most massive**
- **Spread in chemical composition**
- **Probable spread in age**
- **Anomalous branch**
- **Ellipticity**
- **Probable differential reddening**

Bedin et al. (2004) double MS in _ Cen



Piotto et al. (2005)

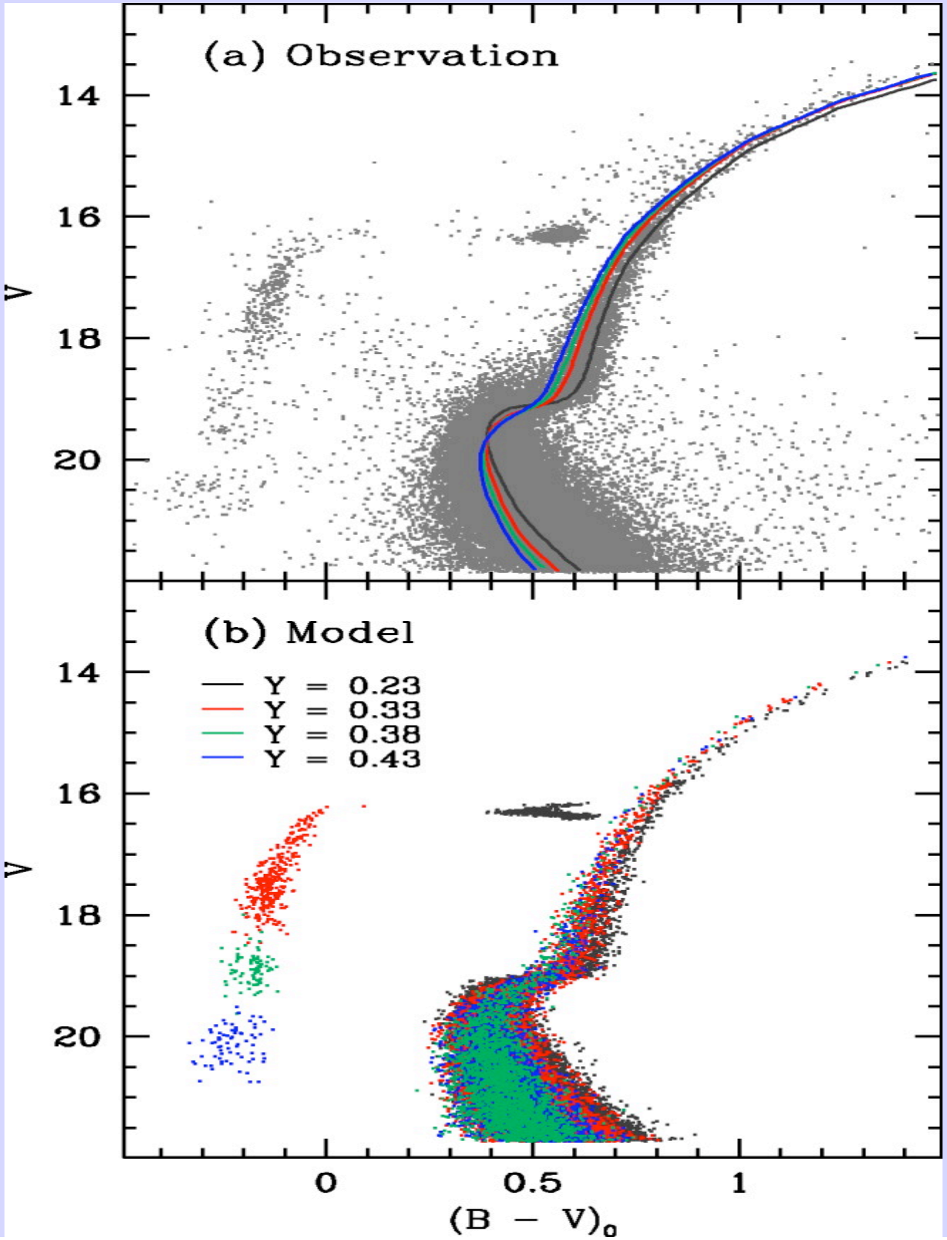




"The blue MS can only be reproduced by adopting **0.35≤ Y ≤ 0.45**"

Lee et al. (2005) EHB stars in 2808 & in _ Cen

Working hypothesis:
He-enriched population
HB morphology
&
Abundance Unticorrelation
C,N,O,Mg,Al
[D'Antona et al. 2005]



Numero Pondere et Mensura deus omnia condidit

Quest for complete star counts of HB, RG & MS stars in _ Cen

Photometry of HB stars in M3

(STERNHAUFEN [star cluster] by P. ten Bruggencate 1927)

Direktor der Univ. Sternwarte in Gottingen based on photographic plates provided by Shapley

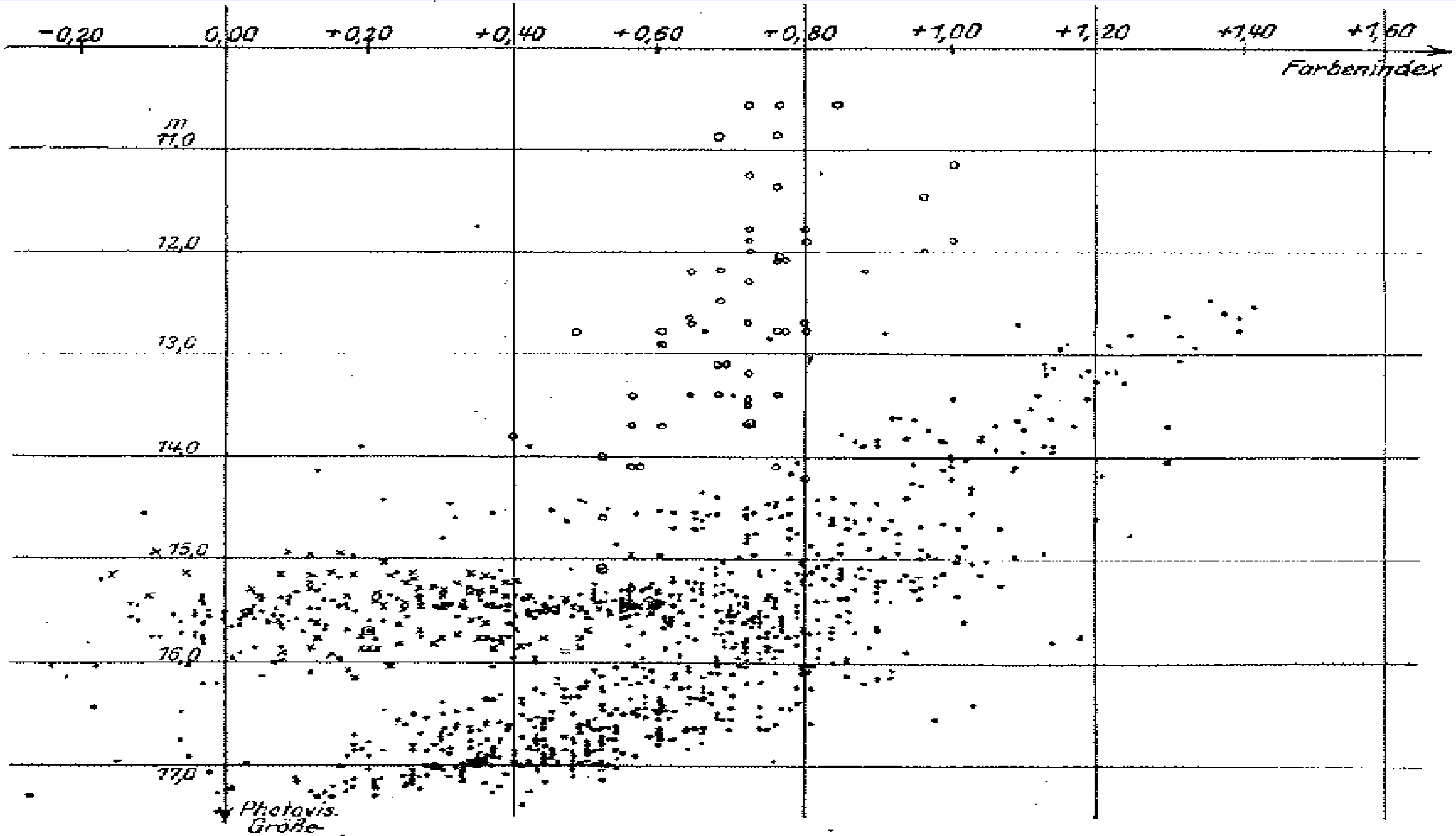
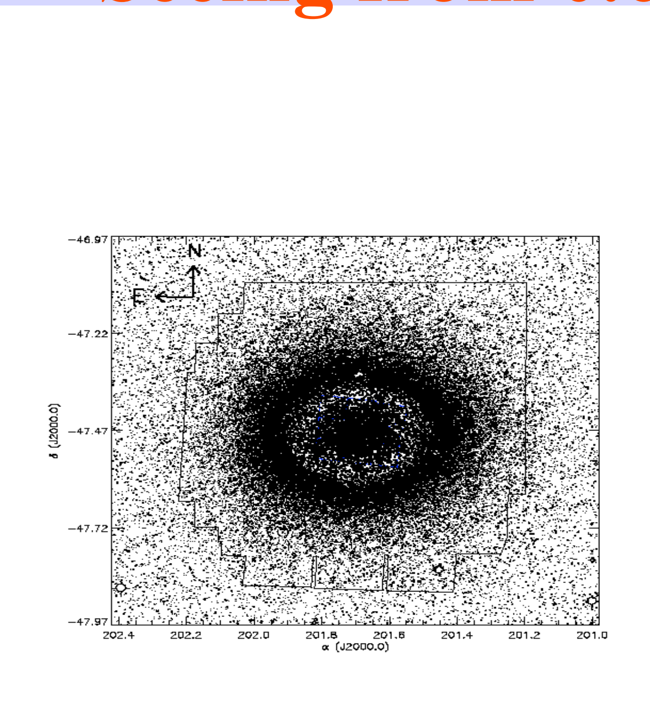


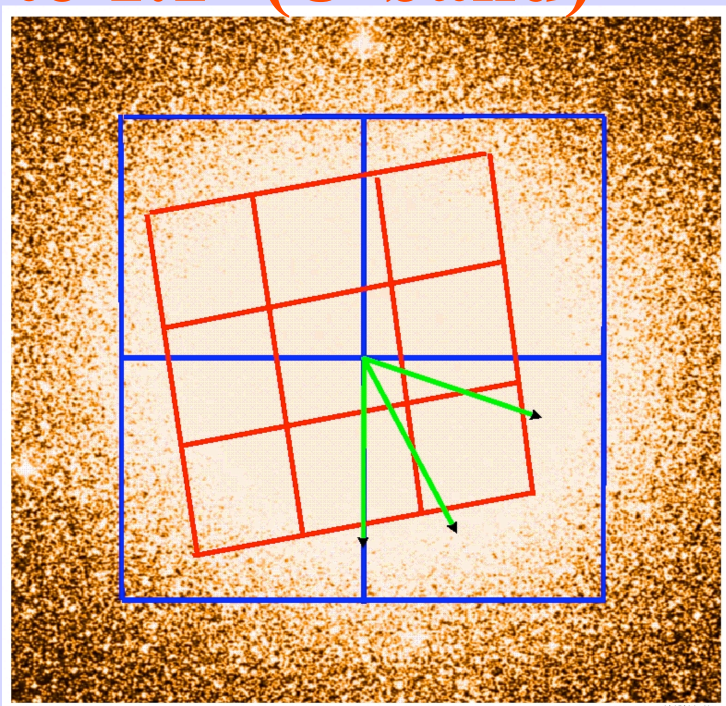
Abb. 21. Farbenhelligkeitsdiagramm des Kugelhaufens Messier 3.

Optical Multiband survey of _ Cen

ACS@HST → [B,R,H__] 3x3 mosaic across the center (10x10 arcmin^2) 108 images (t_exp 8, 340, 440 s)

WFI-2.2 ESO/MPI → [U,B,V,I] different pointigs (42x48 arcmin^2) 89 shallow & 35 deep images Seeing from 0.6’ (I-band) to 1.1’ (U-band)





Simultaneous reduction of Space & ground-based data: DAOPHOT/ALLFRAME

Characterization (positional effect) of the WFI in U,U_new, B,B_new, V, I

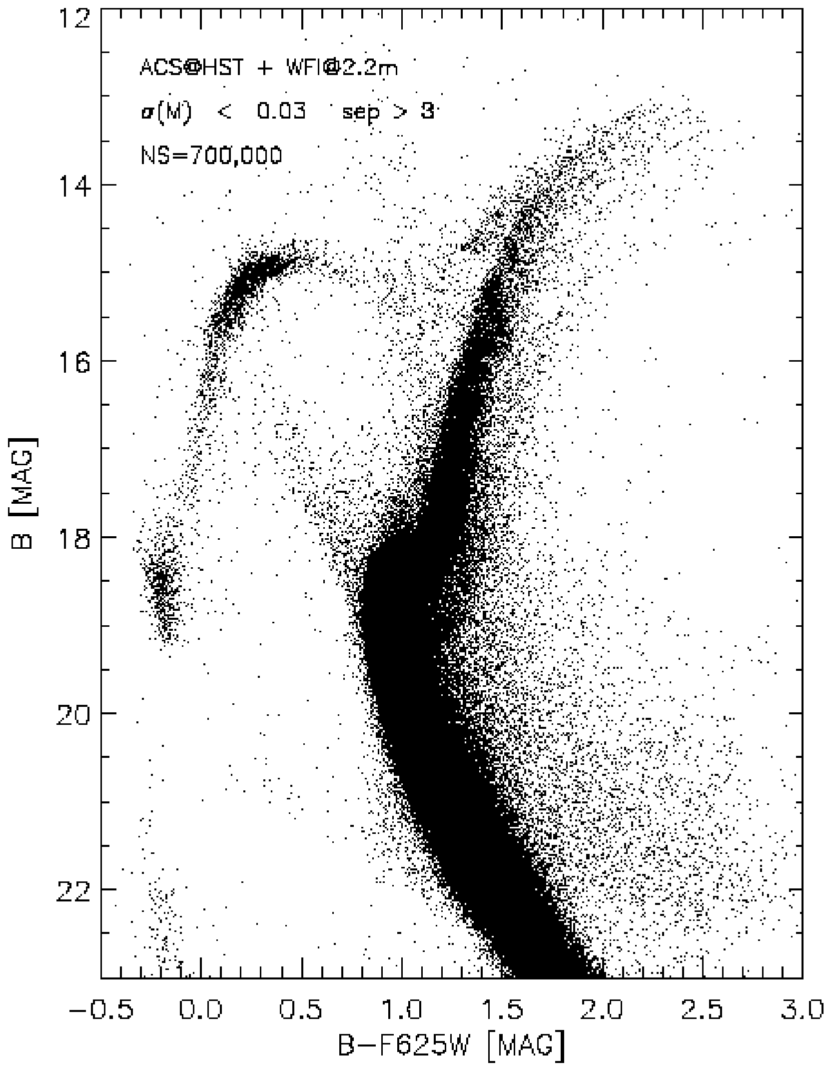
ACS@HST → 1.3 Million stars

WFI-2.2m ESO/MPI → 0.6 Million stars

FINAL CATALOGUE 1.7 million stars

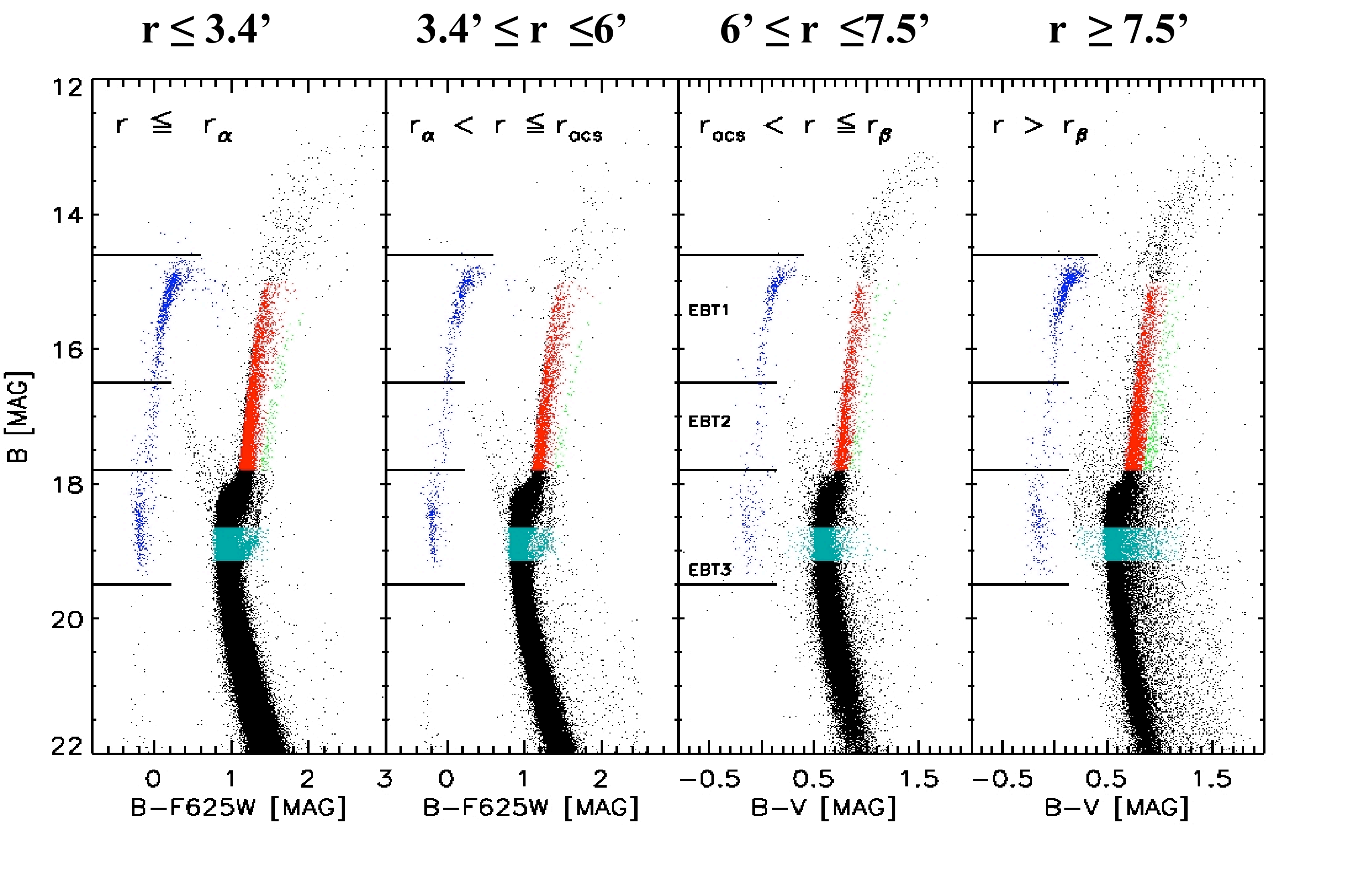
Just a tidbit (!)

Good statistics → sampling of fast evolutionary phases



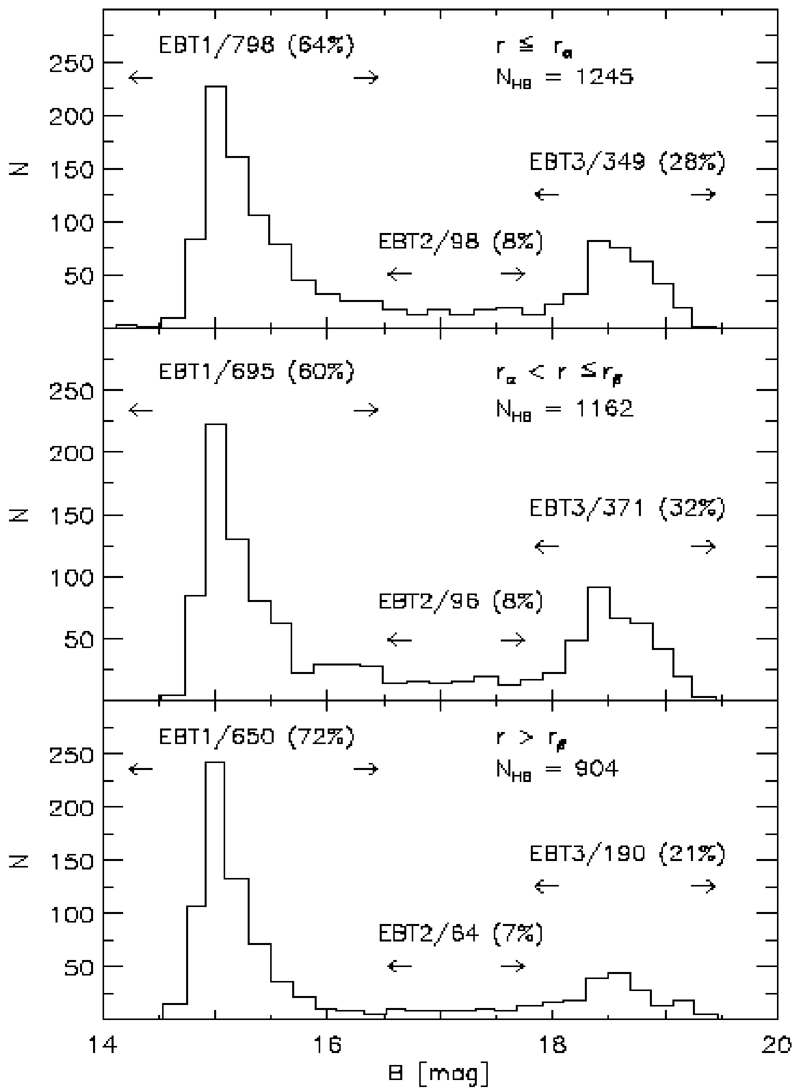
Radial dependence of evolved populations

3,200 HB stars – 12,500 RG stars (below the bump)

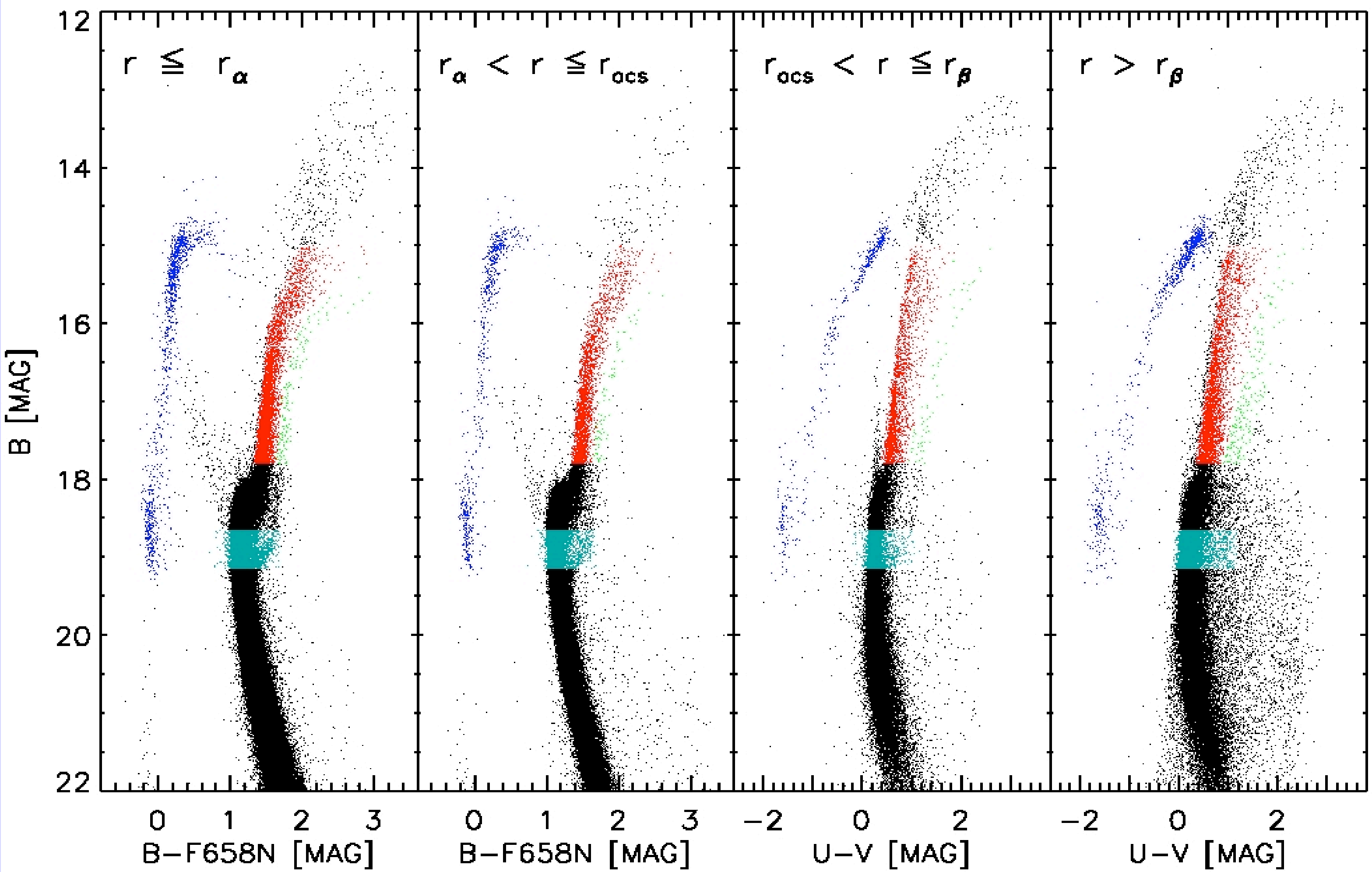


When moving from the center to the outer reaches of the cluster

The fraction of EBT1 stars increases, while the fraction of EBT3 stars decreases

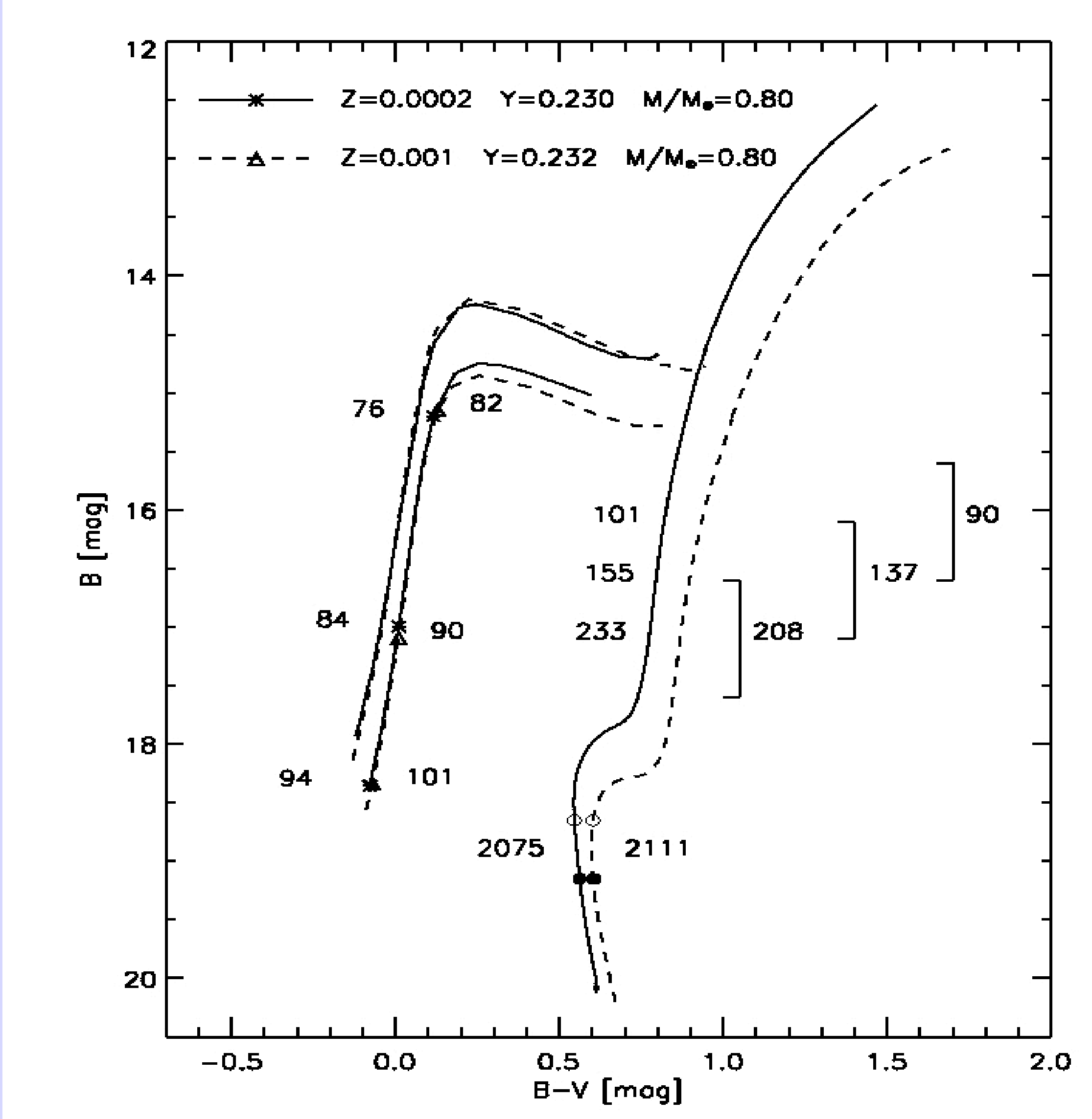


DOUBLE CHECK USING DIFFERENT COLORS



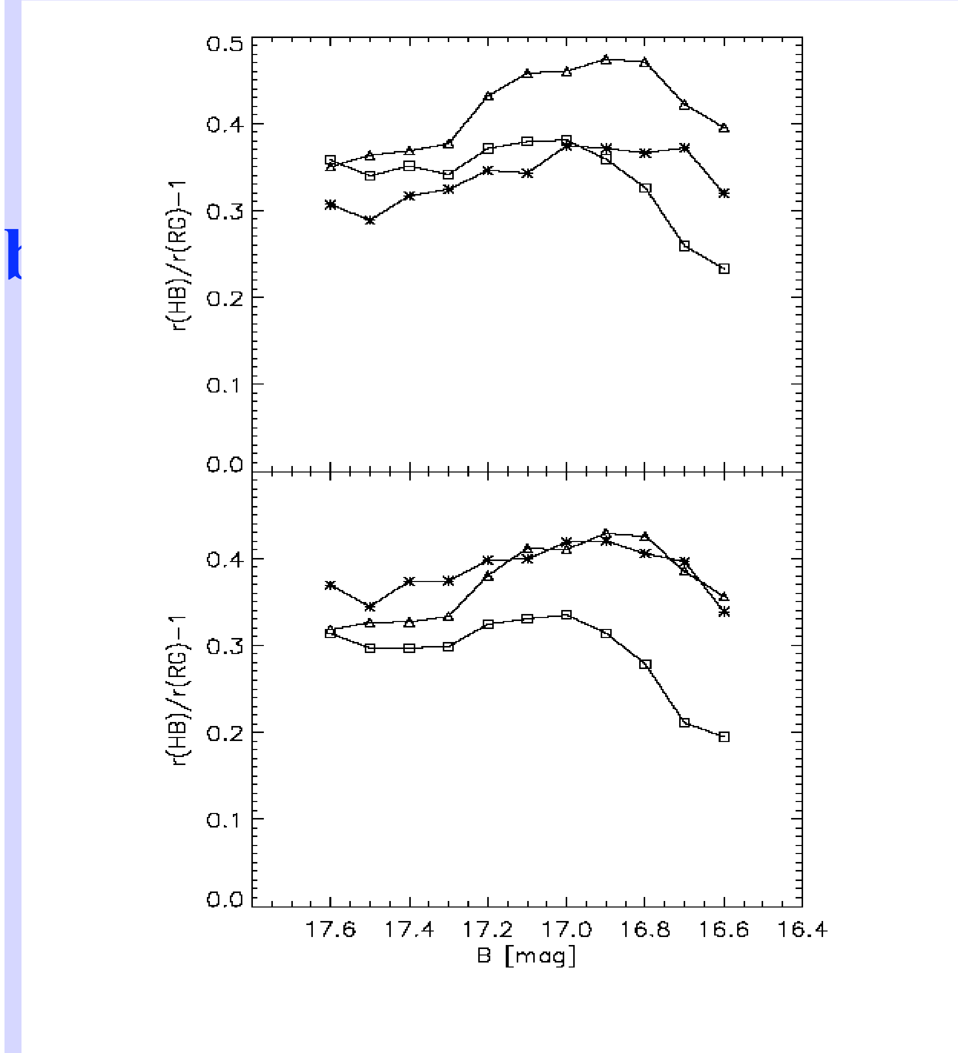
Setting the "theoretical clock"

M/Mo=0.80
Age ~ 12 Gyr
No mass-loss - diffusion
Pisa Evolutionary Code
Cariulo et al. (2004)

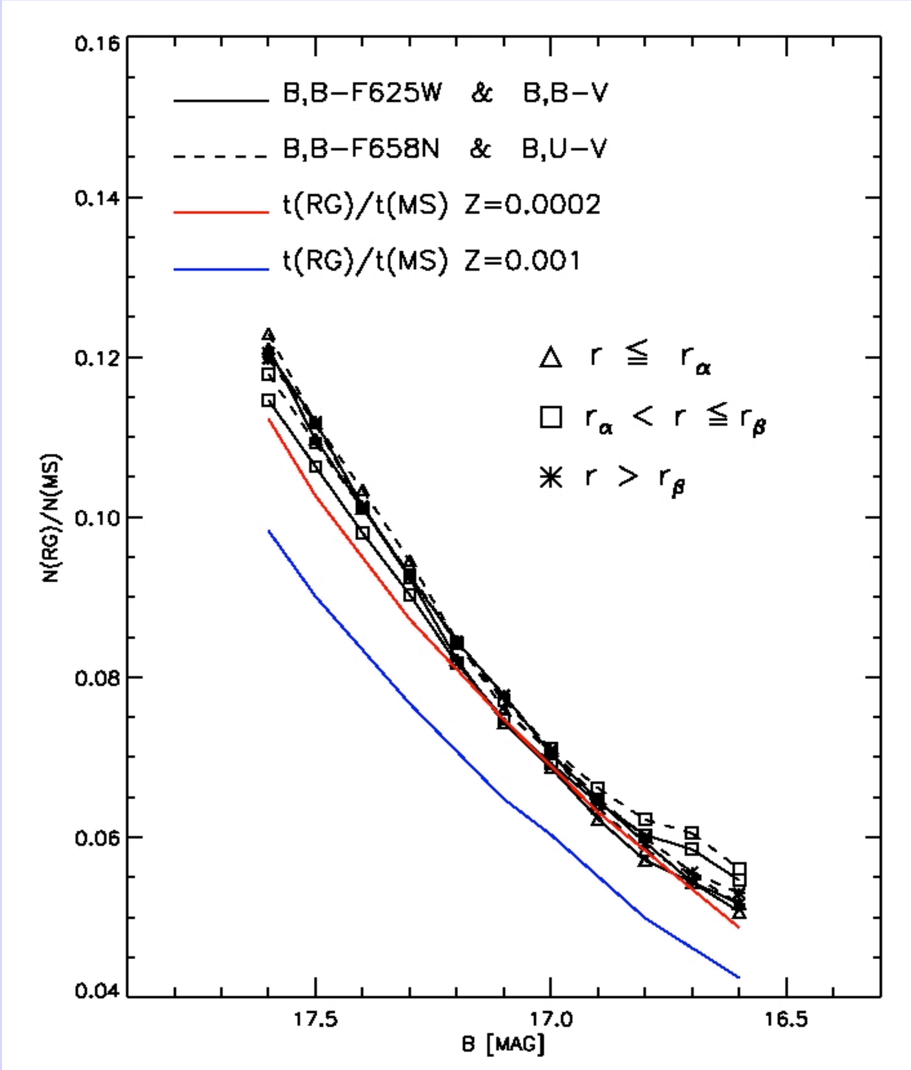


STAR COUNTS

r(HB)/r(RG)-1 vs B



NRG/NMS vs B



N_{HB}/t_{HB} = **14.8** N_{MS}/t_{MS} = **9.5** [r ≤ r_]

N_{HB}/t_{HB} =**13.7** N_{MS}/t_{MS} = **9.3** [r_ ≤ r ≤ r_]

N_{HB}/t_{HB} =**10.9** N_{MS}/t_{MS} = **7.3** [r ≥ r_]

≈39 HB per Myr ≈25 MS per Myr

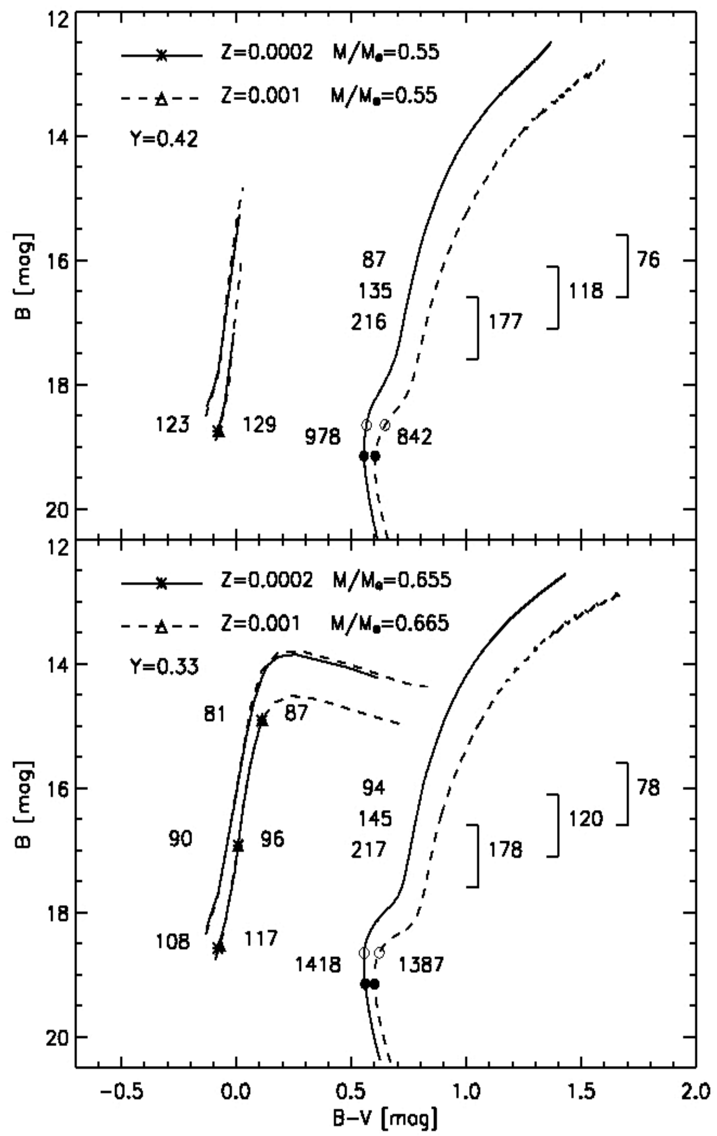
Observed HB/MS star counts are ≈35% larger than observed ones

He-mixed populations

70% canonical +

30% He-enriched

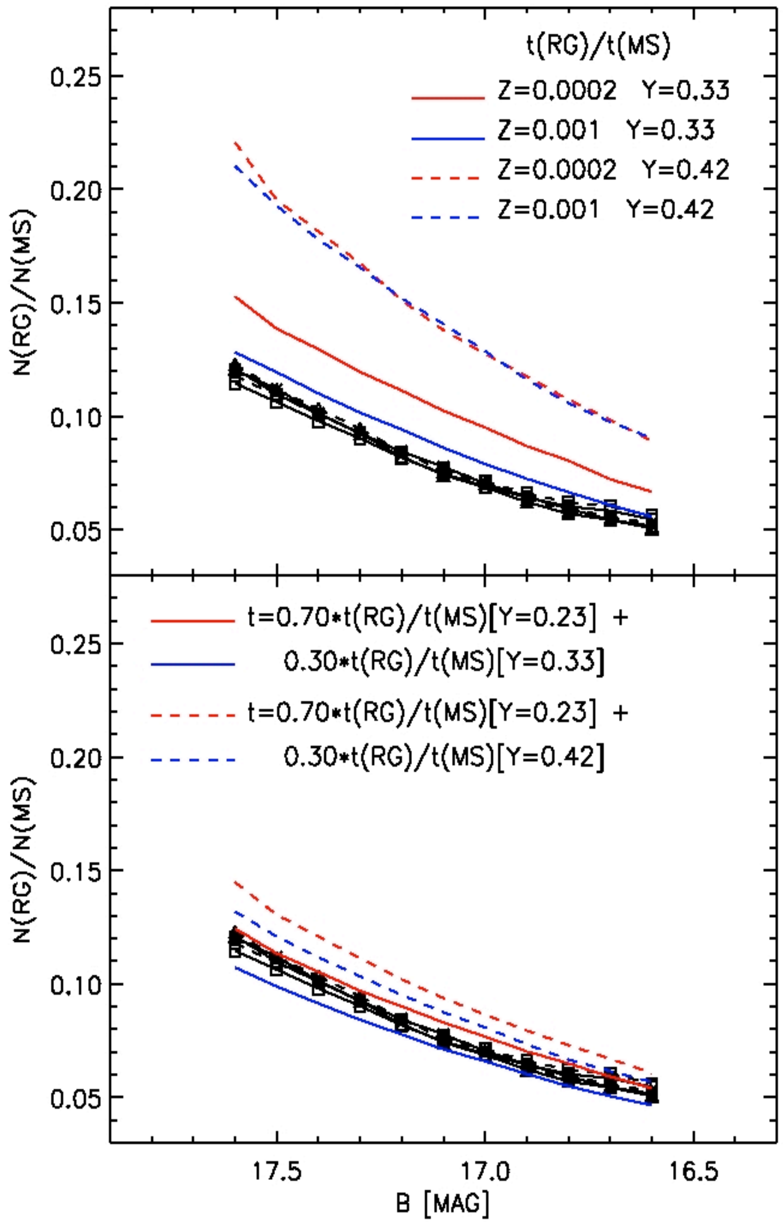
New theoretical clocks at fixed cluster age and different He content



N_{RG}/N_{MS}

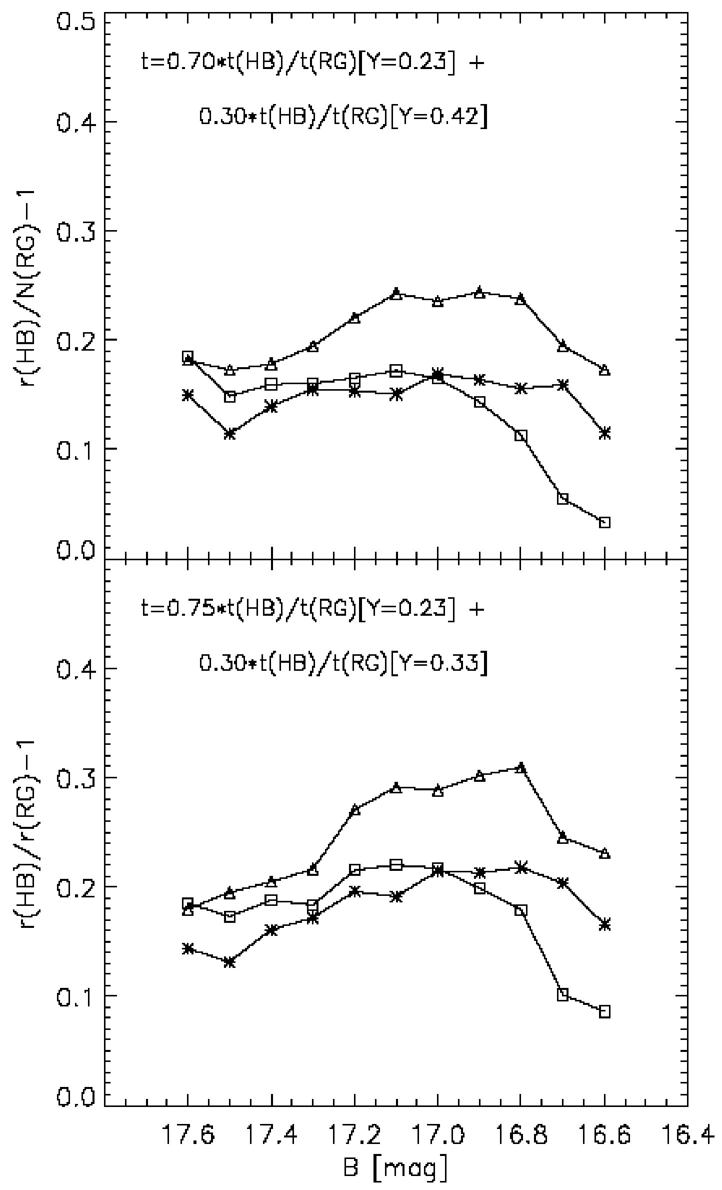
Marginally dependent on He content

Independent support to the weak dependence of the LF, below the bump, by Salaris et al. (2006)



r_{HB}/r_{RG} (He-mixed)

Is **15%-25%** higher than observed for Y=0.42



Slightly smaller discrepancy (15%-20%) for Y=0.33

$\langle N_{HB}/t_{HB} \rangle \approx$ **38** for **70% Y=0.23 + 30%Y=0.33**

$\langle N_{HB}/t_{HB} \rangle \approx$ **39** for **70% Y=0.23 + 30%Y=0.42**

$\langle N_{MS}/t_{MS} \rangle \approx$ **28** for **70% Y=0.23 + 30%Y=0.33**

$\langle N_{MS}/t_{MS} \rangle \approx$ **30** for **70% Y=0.23 + 30%Y=0.42**

Observed HB/MS star counts are ≈33% (Y=0.33) & ≈24% (Y=0.42) larger than observed ones

r_{HB}/r_{MS}

very robust observational parameter

#) Y _ **then** t_{MS} & t_{RG} _ **while** t_{HB} _

#) HB stars are not affected by field star contaminations

#) MS are marginally affected and if any the effect goes in the opposite direction(!)

Working hypothesis: **Breathing Pulses**

Auto-trascinamento del nucleo convettivo

Castellani et al. (1985), Caputo et al. (1989), Straniero et al. (2003)

Stellar ROTATION goes in the opposite direction

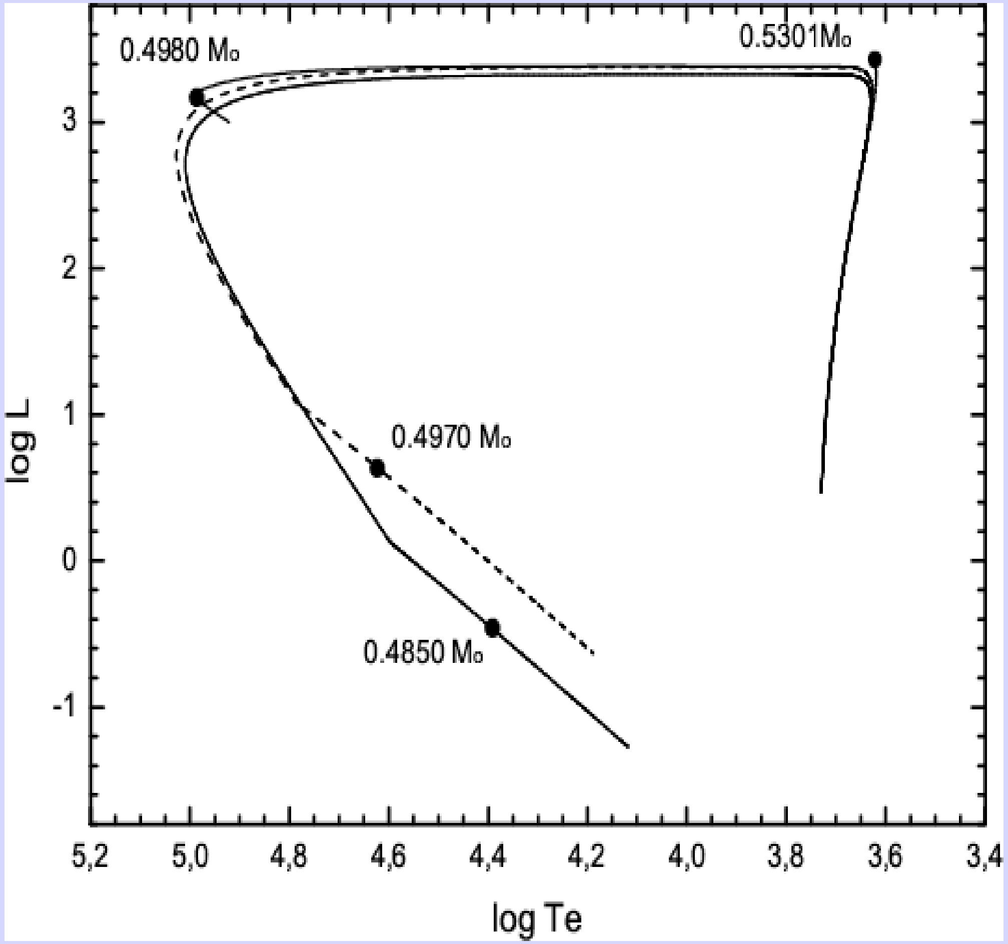
Mc_ L_{HB}_ _HB_

Working hypothesis: HOT He-FLASHERS

Violent mass-loss event along the RGB (binarity)

Castellani & Castellani (1993), D'Cruz et al. (1996)
Sweigart (1997), Castellani et al. (2006)

Increase in EBT3 stars might also be explained as a coalescence of He-core WDs (Iben 1991)

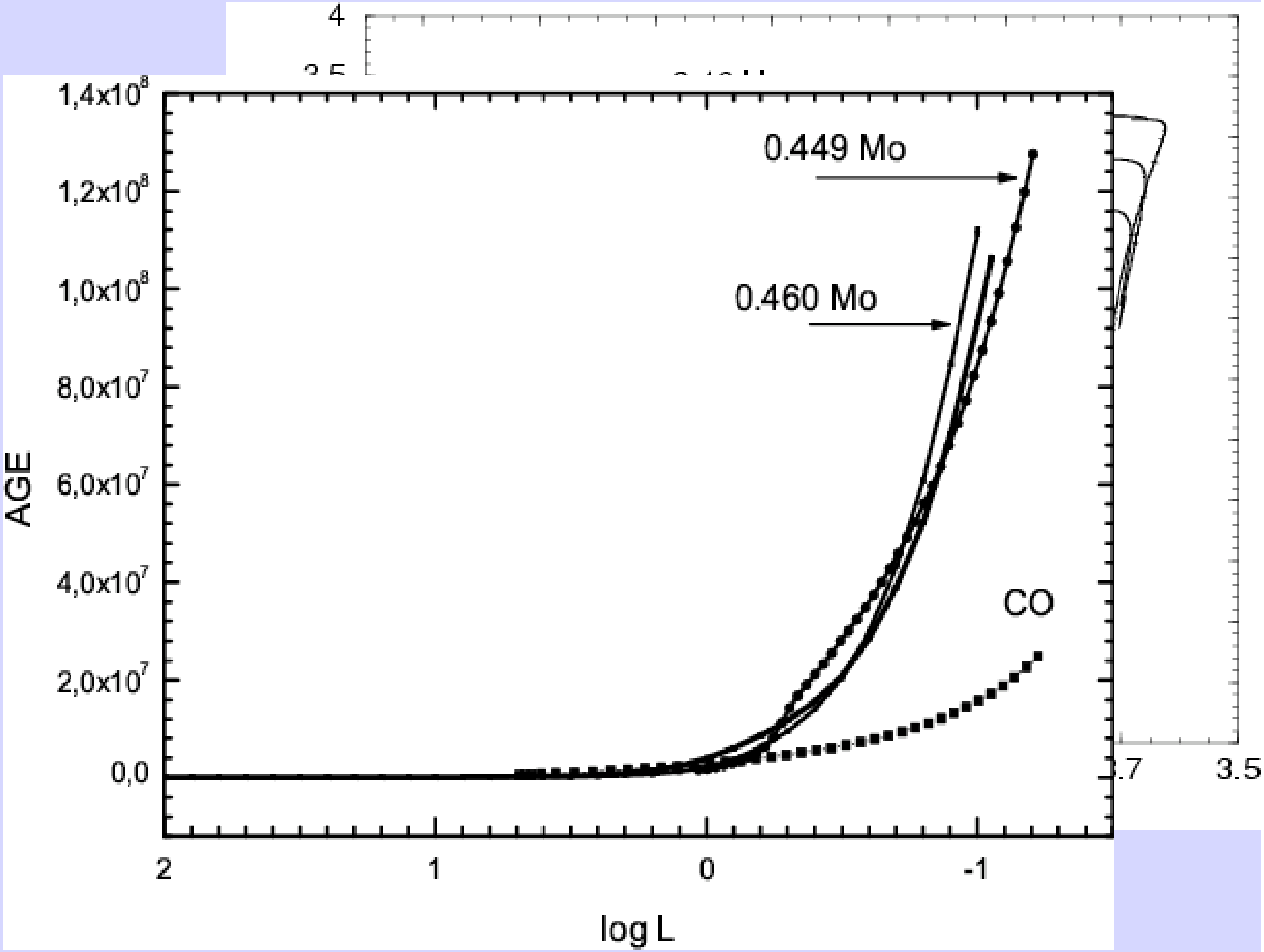


IMPACT ON FINAL EVOL. PHASES

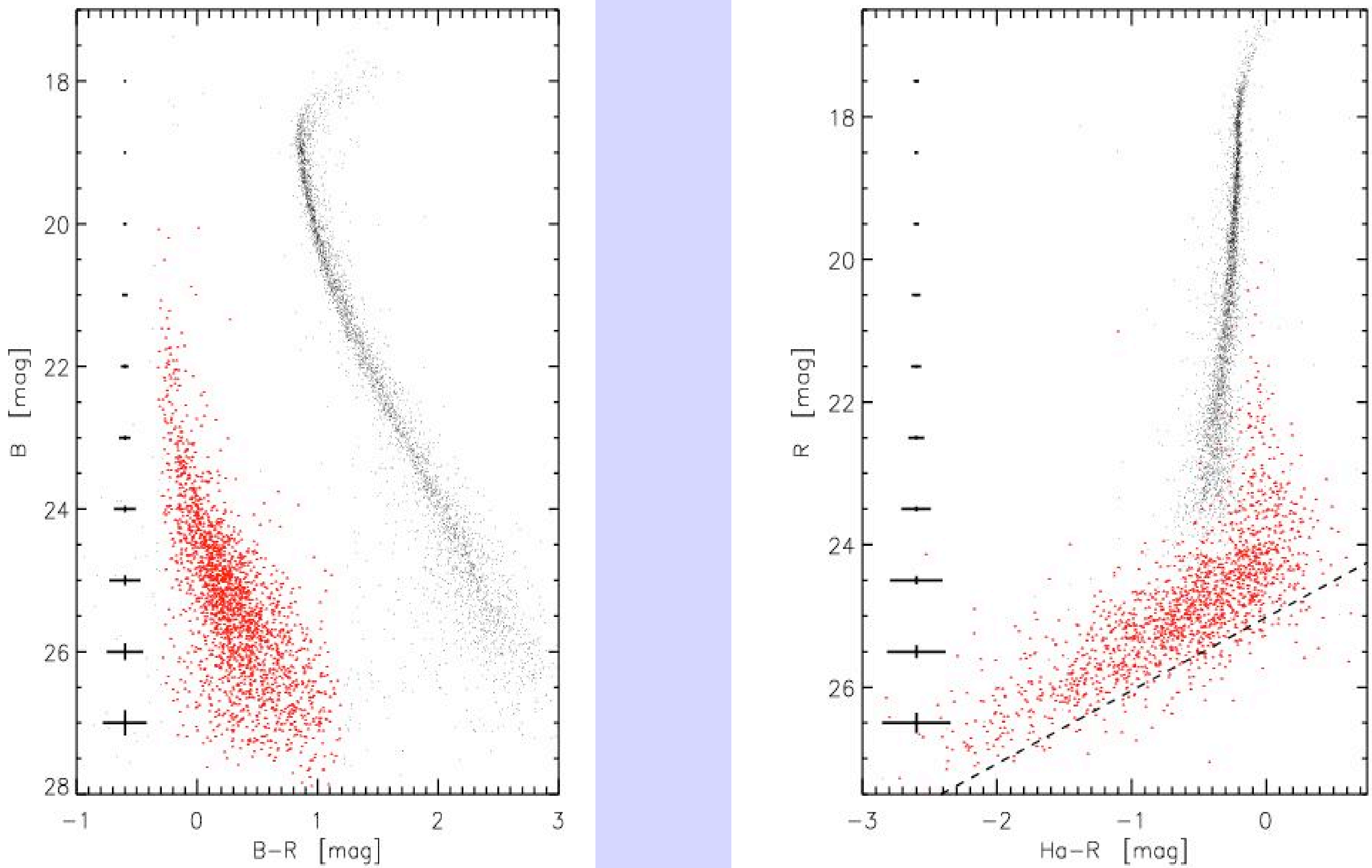
He-mixed scenario → puzzling!!

Canonical He → an incrase in N_{HB} & N_{AGB}
and/or in He-core WDs

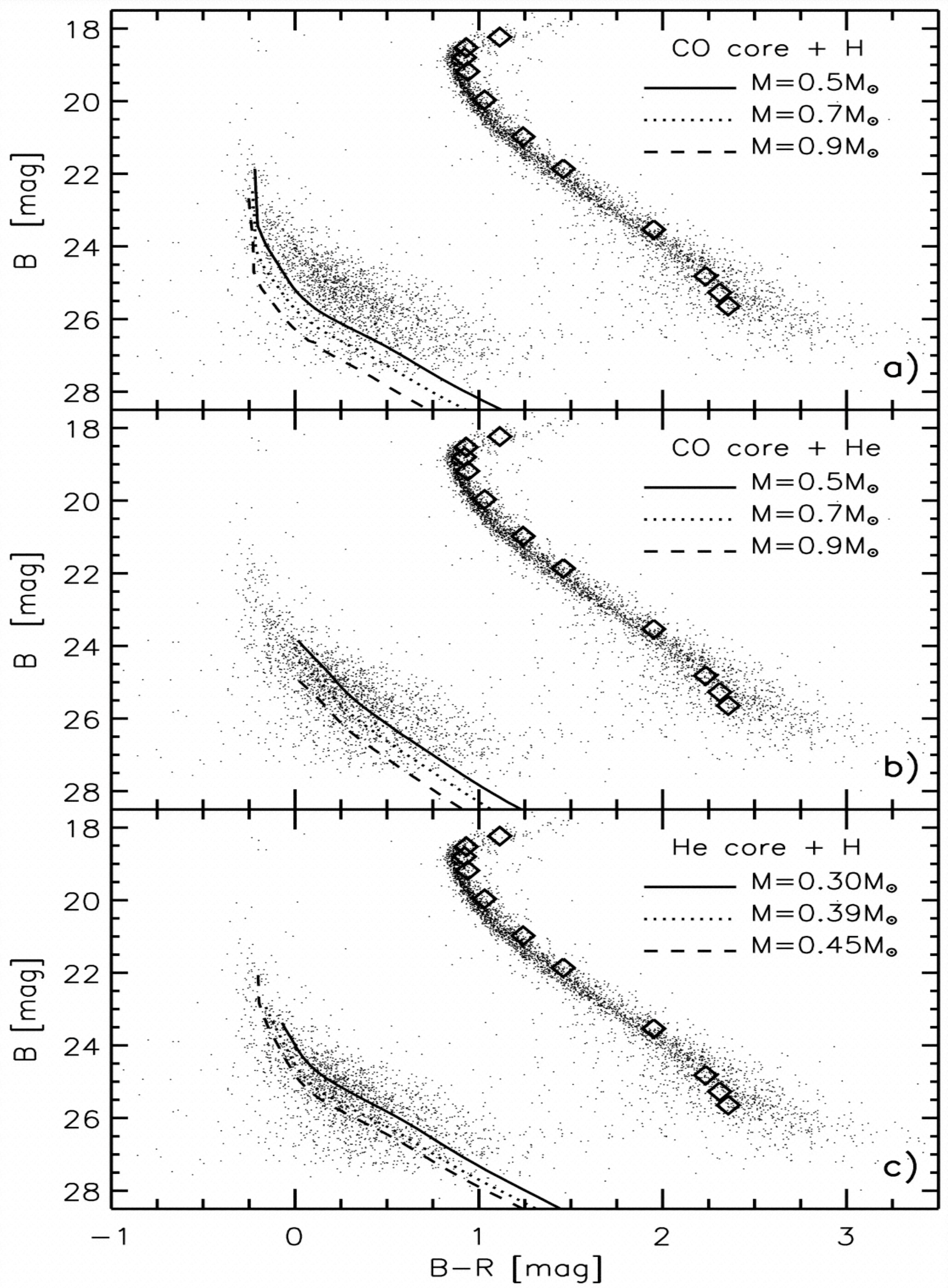
plain physical arguments …

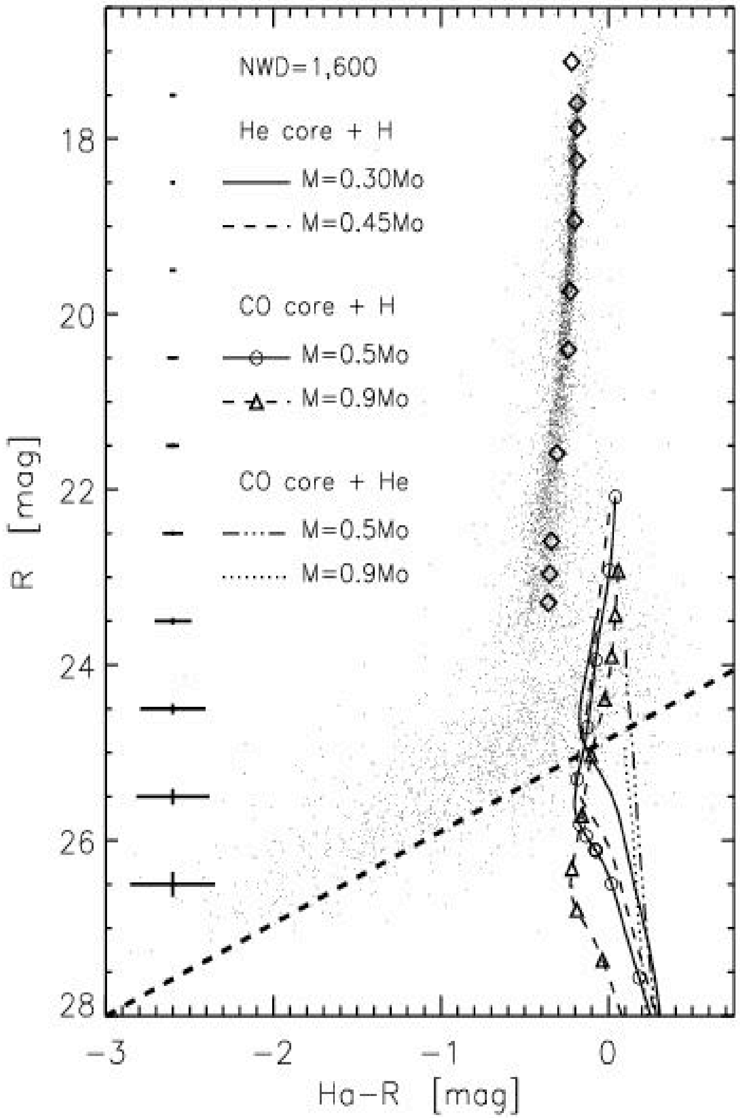


Castellani et al. (2006)

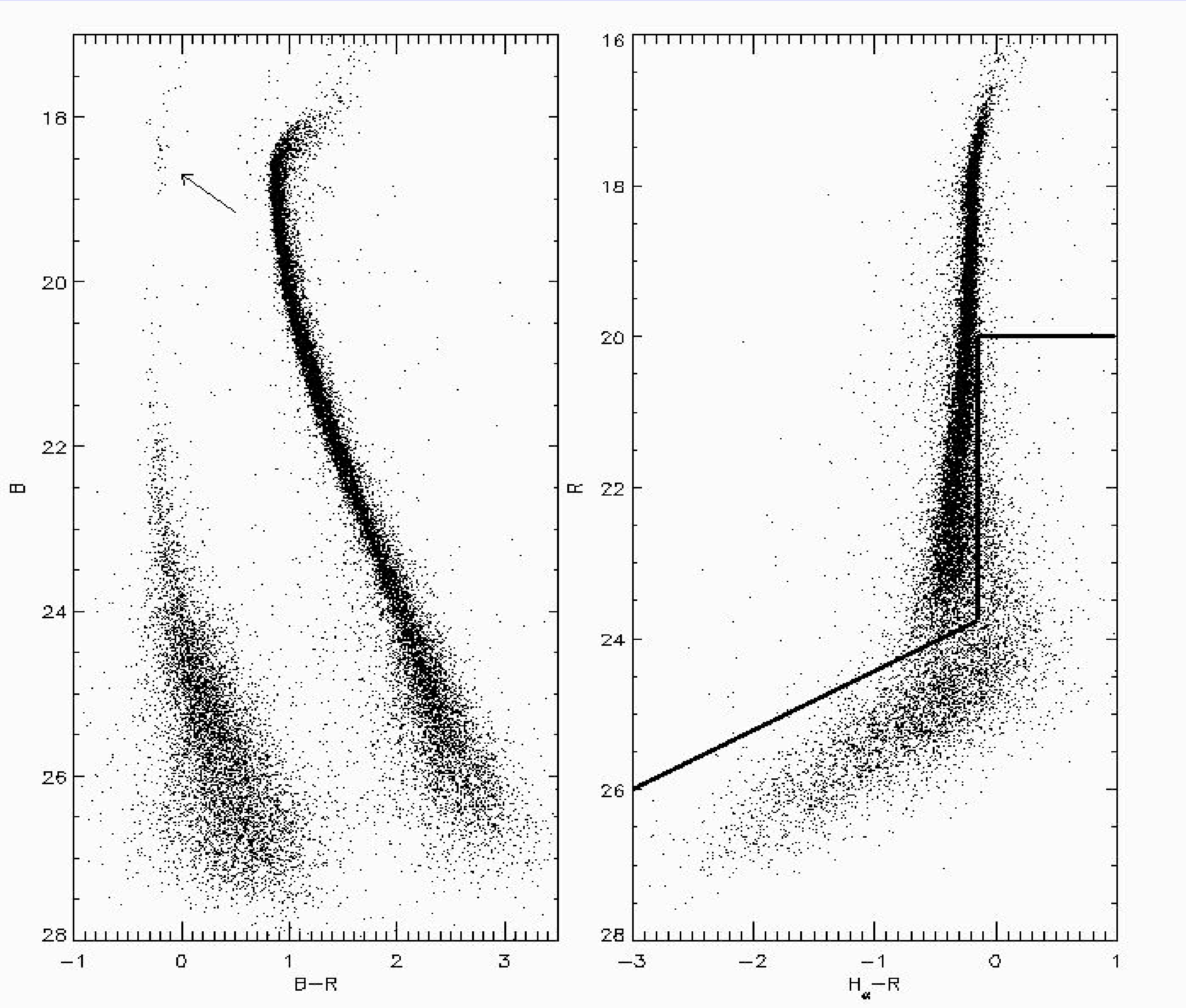


ROMAFOT 3 out of 9 ACS pointings more than 2000 WDs
Monelli et al. (2005)





Cooling sequences by Serenelli et al. 2002 + atmospheres by Bergeron et al. 1995)



ROMAFOT 8 out of 9 roughly 7000 WDs !

BIG PROBLEM:

Who is Who along the WD cooling sequence ?

He-core WDs can only be produced by binaries

BUT

_ Cen has a low-central density → the binaries should be either small or primordial

Spectroscopic Follow-Up: (FORS2+Giraffe)@VLT
For the two dozen brightest WDs

(DIATRIBE with the TAC!!)

Different Circumstantial evidence

IF

He-mixed populations are connected with MASSIVE STAR CLUSTERS →

→there is no good reason why the same phenomenon should not occur in the BULGE

→ _Y/_Z_(≈70) ←

→The UV-emission from old populations should also be significantly higher in ellipticals & bulges

CONCLUSIONS: I

→Evidence for an excess of HB stars in the core

→ Some RG stars might not approach the He-core flash ending up as Hot He-flashers and/or He-core WDs.

→The QUEST/HUNT for an accurate (a few %) measurement of **Yp** abundance **& _Y/_Z** (a factor of 2) is open !!!!

→**The R parameter could be affected by systematics {mimics a higher He content!}**

CONCLUSIONS: II – _ Cen

→ **Empirical evidence based on HB, RG, and MS star counts do not support the hypothesis that _ Cen hosts a large fraction (≈30%) of He-enriched stars (Y≥0.33).**

→**The HB morphology changes with the radial distance**

→ **EHB stars are centrally concentrated (Bailyn al 1992)**

Felix qui potuit rerum cognoscere causas (I. N.)

Future Developments

PHOTOMETRY

Mosaic U-band VIMOS@VLT data
Mosaic NIR SOFI@NTT + ISAAC@VLT
Stroemgren photometry (u,v,b,y) [M. Hilker]

SPECTROSCOPY

FLAMES@VLT for BS (L. Freyhammer) & hot HB (50%, S. Moehler)

Credits

- **A. Calamida (INAF-OAR), M. Monelli (IAC)**
- **Rome: Buonanno, Caputo, Castellani, Corsi, Ferraro, Iannicola, Pulone**
- **Pisa: Degl'Innocenti, Prada Moroni**
- **Teramo: Piersimoni, Del Principe**
- **Trieste: Nonino, Vuerli**
- **FC: Stetson (DAO), Freyhammer (UK)**

GRAZIE VITTORIO