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Exotic populations in Galactic Globular Clusters: the Blue Straggler Stars

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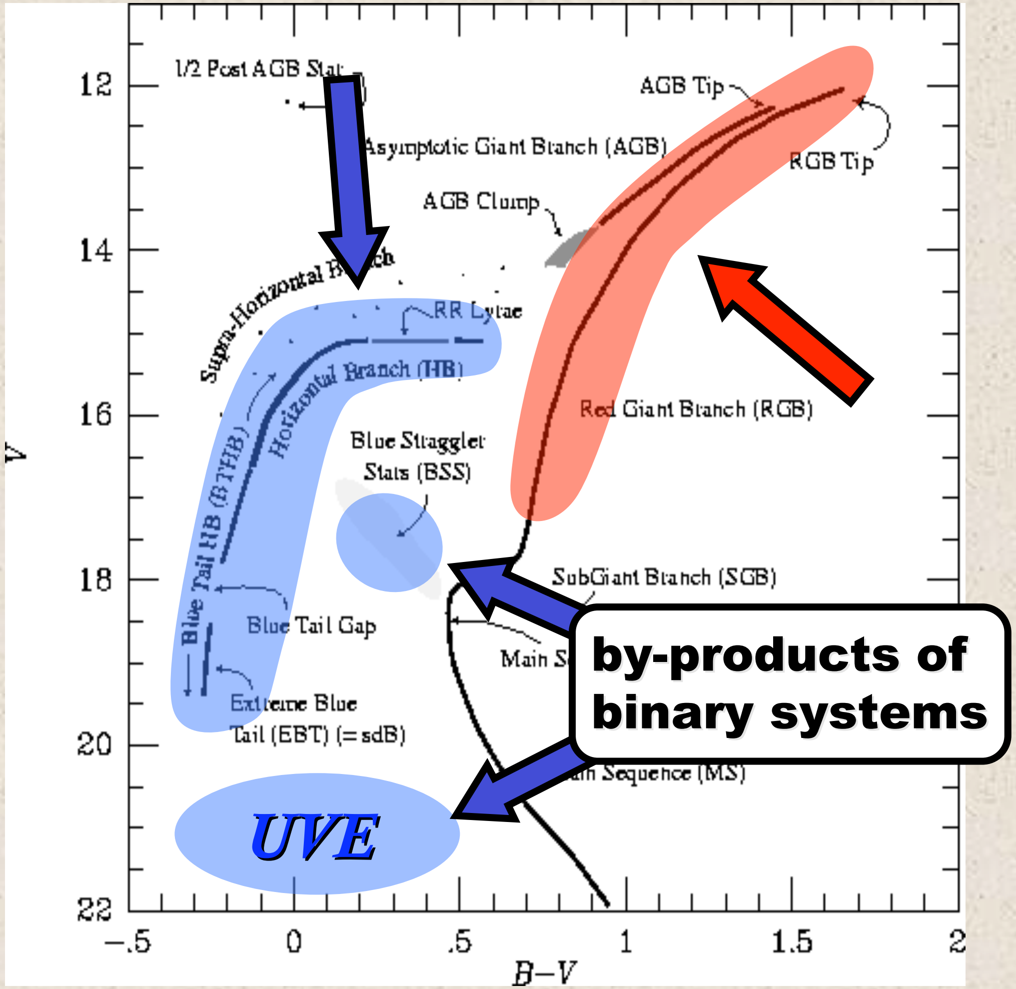
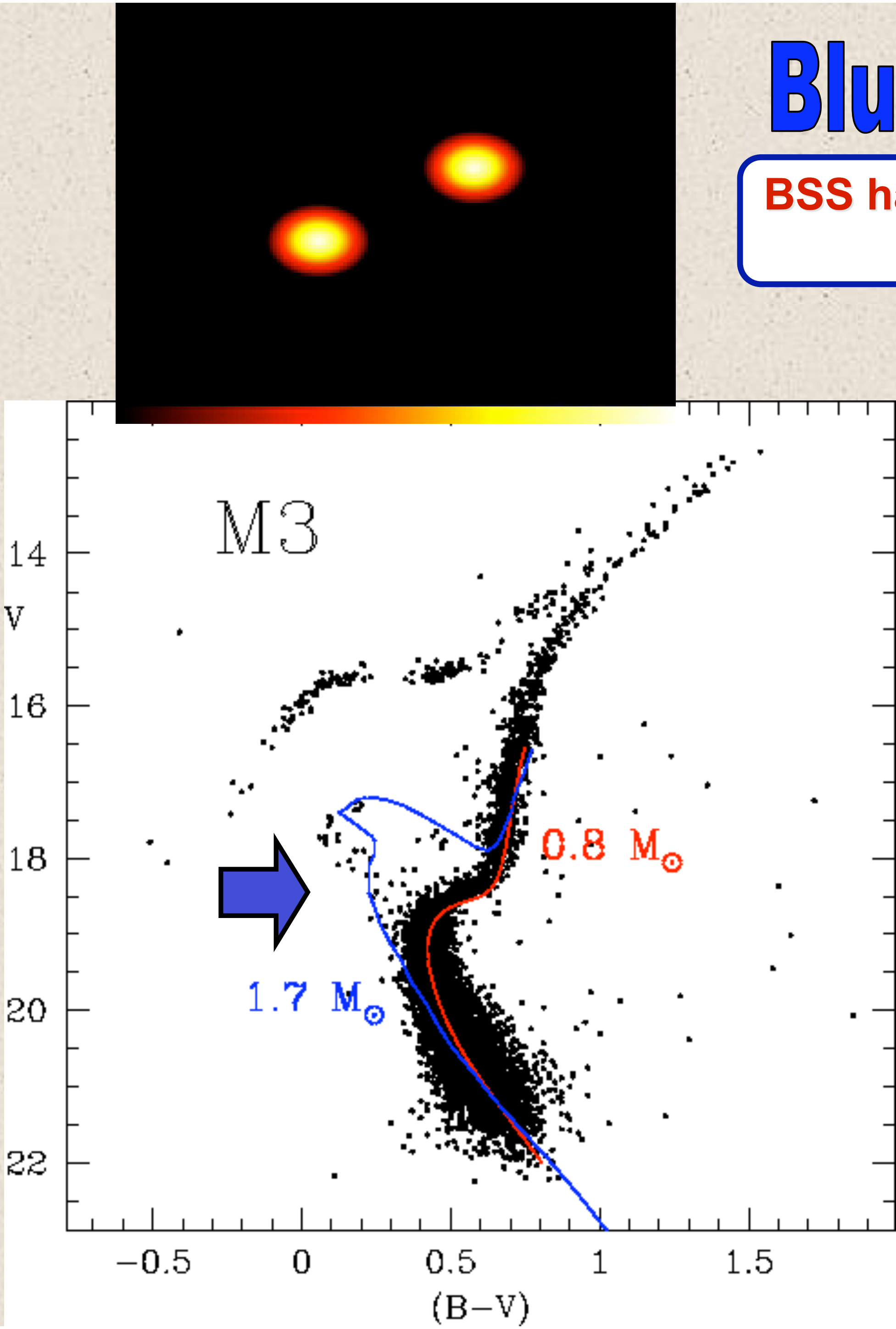
Exotic populations in the CMD

ANOMALOUS sequences
as
Blue Stragglers Stars
and UVE

"perturbations"
of "canonical"
evolutionary sequences





Blue Straggler Stars

BSS have been detected for the first time by Sandage (1953)

according to their position in the CMD, *BSS* should be *more massive* than *normal* stars (see also Shara et al 1997)

merge of 2 low-mass stars → unevolved, massive star

primordial Binaries

...evolving in isolation In low density GCs

PB-BSS

direct Collisions

..in the central region of high density GCs

COL-BSS

BSS → **crucial link between stellar evolution & stellar dynamics**

Blue Straggler Stars

loose GGCs
low c, low ρ_0 $\Rightarrow$ natural habitat for *BSS*

<1990

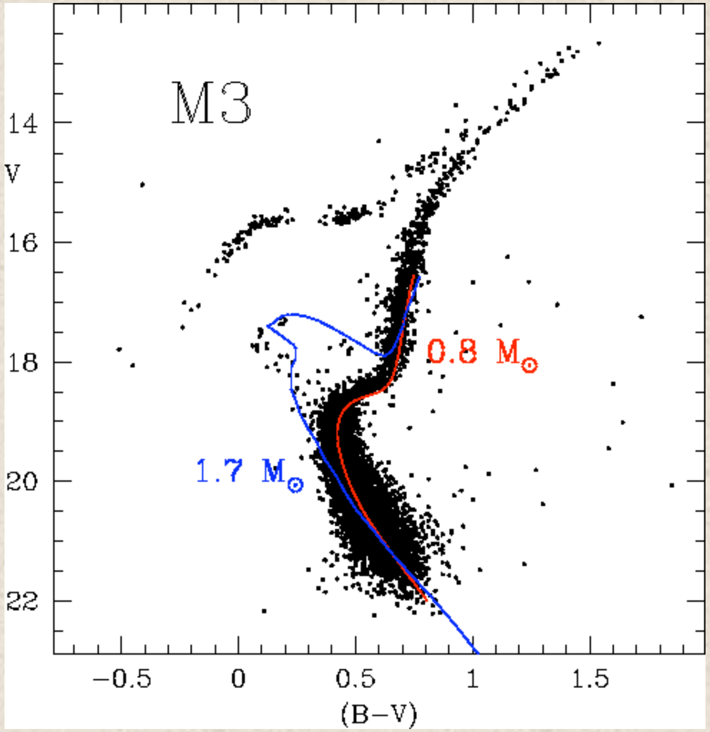
>1990

high resolution studies ⇨
BSS also in the inner region of high density GGCs

- NGC6397 *Auriere et al. 1990*
- 47 Tuc *Paresce et al. 1991*
- M15 *Ferraro & Paresce 1993*

Catalogs:

Fusi Pecci et al. 1992
Sarajedini et al. 1992
Ferraro, Fusi Pecci, Bellazzini 1995
Guhathakurta et al. 1994, 1998
Piotto et al 2004



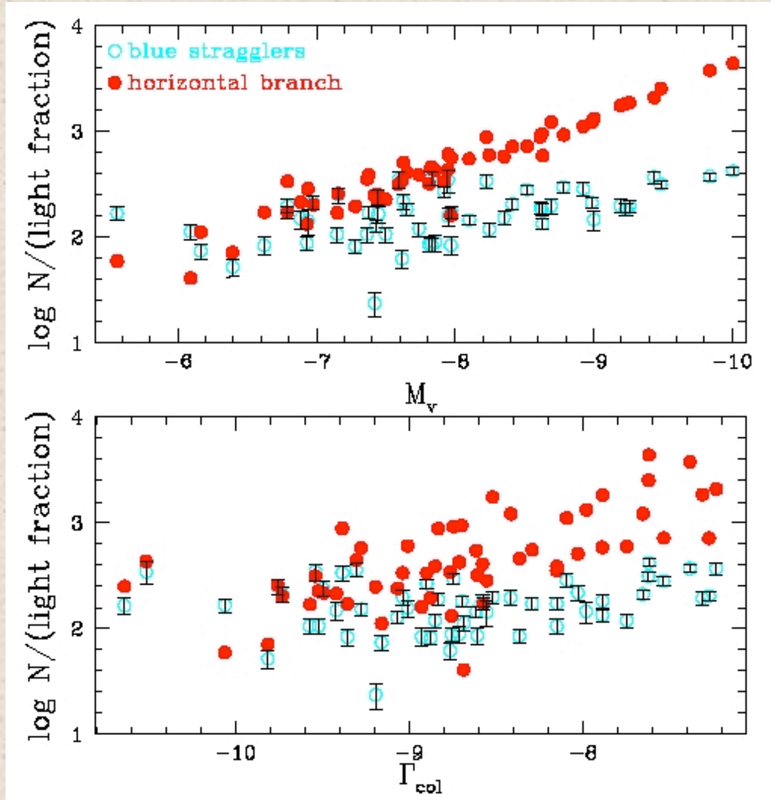
BSS **are a common population of GGCs, found in each cluster properly observed**

Central-BSS catalogs

HST

A Catalog containing 3000 BSS in 56 GGCs from HST optical observations Piotto et al (2004)

See discussion in Davies et al (2004) & Leigh et al (2007), Moretti et al (2008)



N(BSS) varies only by a factor of 10!!!

BSS are produced by both channels (collisions & binary evolution)

According with previous suggestions by Fusi Pecci et al (1993), Baylin (1995), etc…

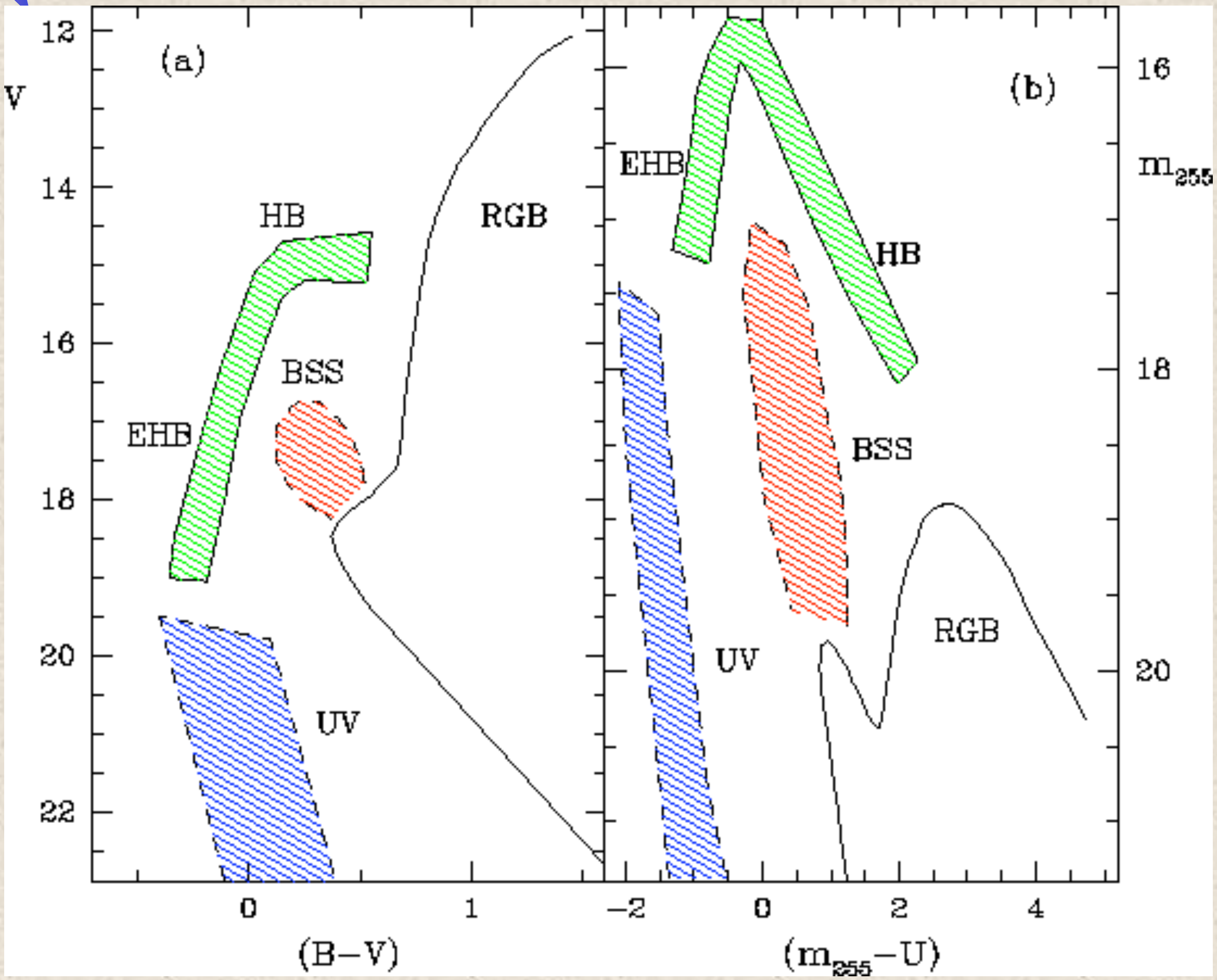
The total number of BSS is independent of cluster mass and collision rate

HST

UV sensitivity , high resolution

⇓

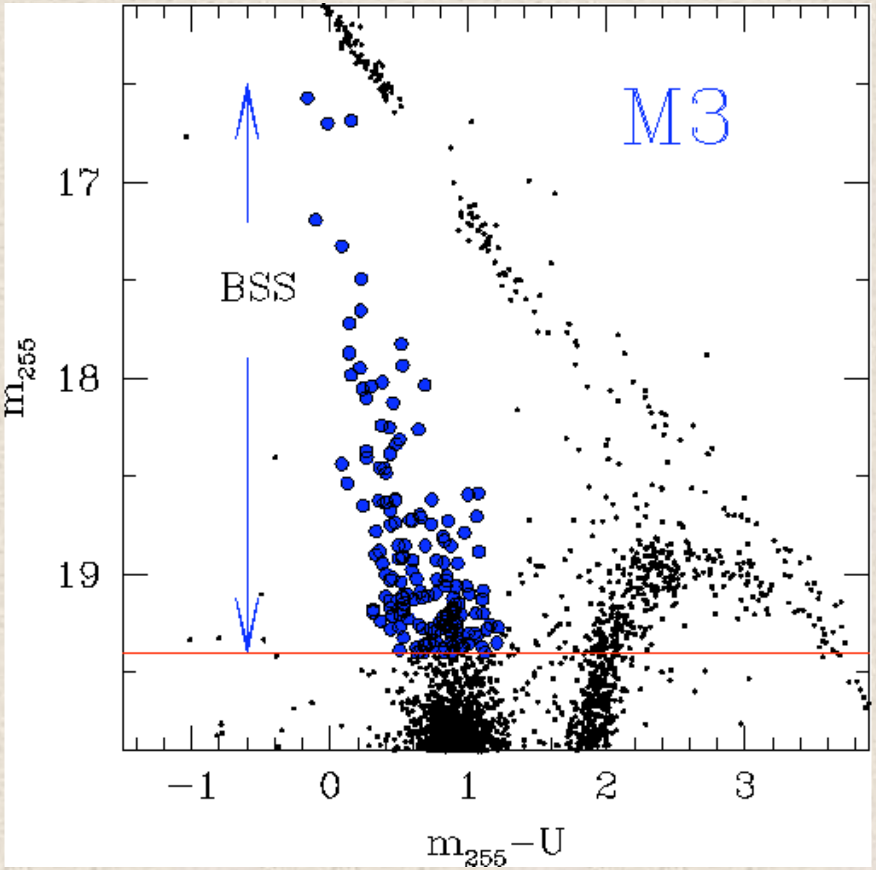
systematic studies of hot SPs
in the core of high density GGCs



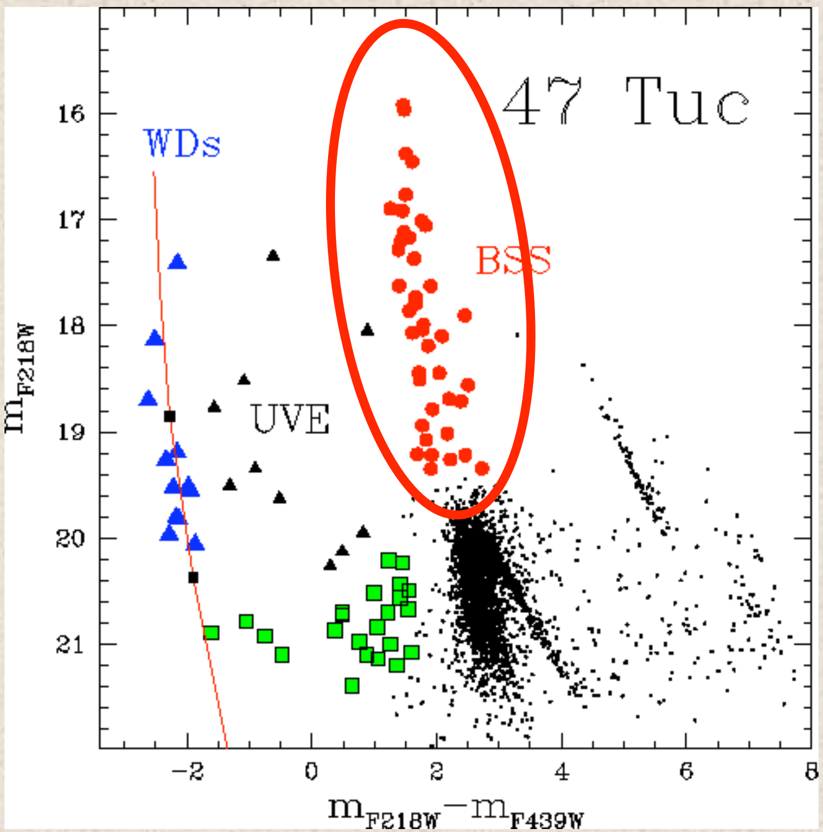
BSS in the UV:

UV-plane **ideal to study the photometric properties of the *BSS* population:**

- the distribution is almost vertical
- span more than 3 magnitudes

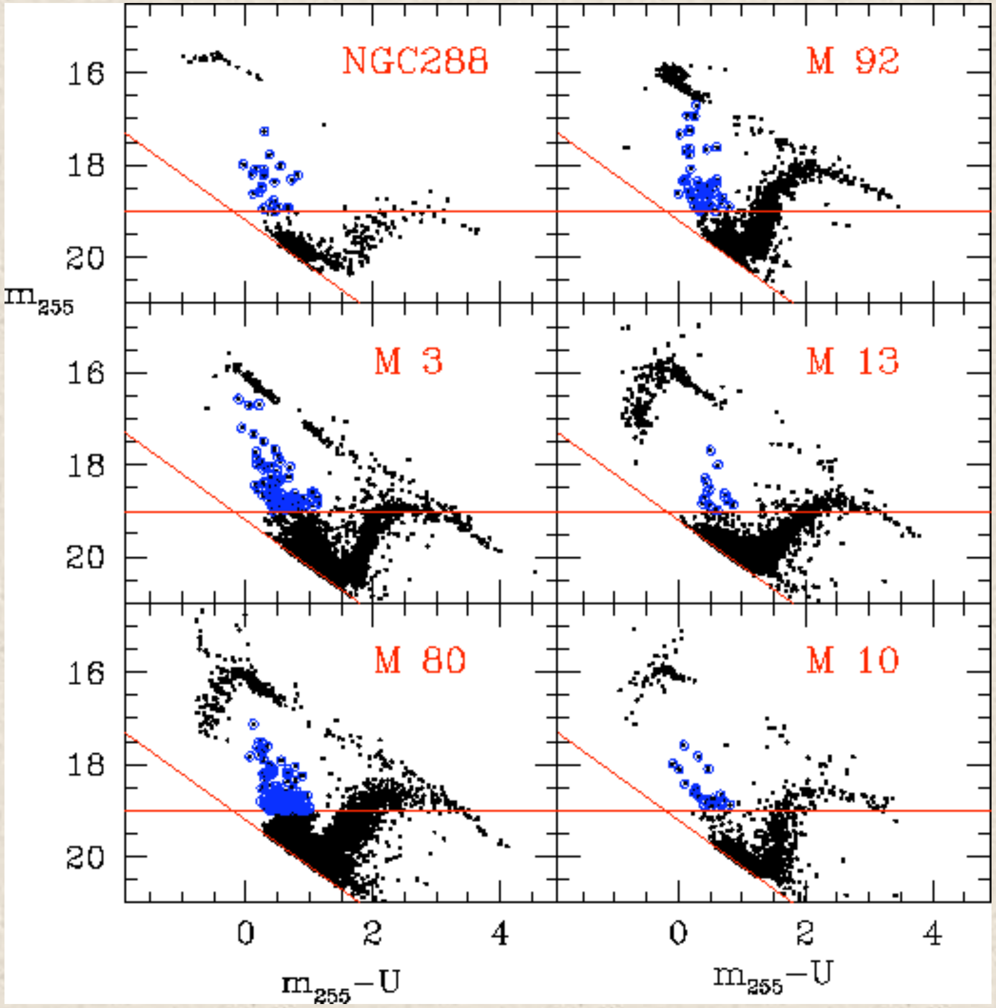


Ferraro et al (1997,A&A,324,915)



Ferraro et al (2001,ApJ,561,337)

Direct comparison of BSS populations



Cluster	$[Fe/H]$	$Log\rho_0$ $[M_\odot/pc^3]$	$Mass$ $[Log(M/M_\odot)]$	d $[Kpc]$	σ_0 $[km/s]$
NGC5272(M3)	-1.66	3.5	5.8	10.1	5.6
NGC6205(M13)	-1.65	3.4	5.8	7.7	7.1
NGC6093(M80)	-1.64	5.4	6.0	9.8	12.4
NGC6254(M10)	-1.60	3.8	5.4	4.7	5.6
NGC288	-1.40	2.1	4.9	8.8	2.9
NGC6341(M92)	-2.24	4.4	5.3	9.0	5.9
NGC6752	-1.60	5.2	5.2	4.3	4.5

N_{BSS} must be normalized to the cluster population

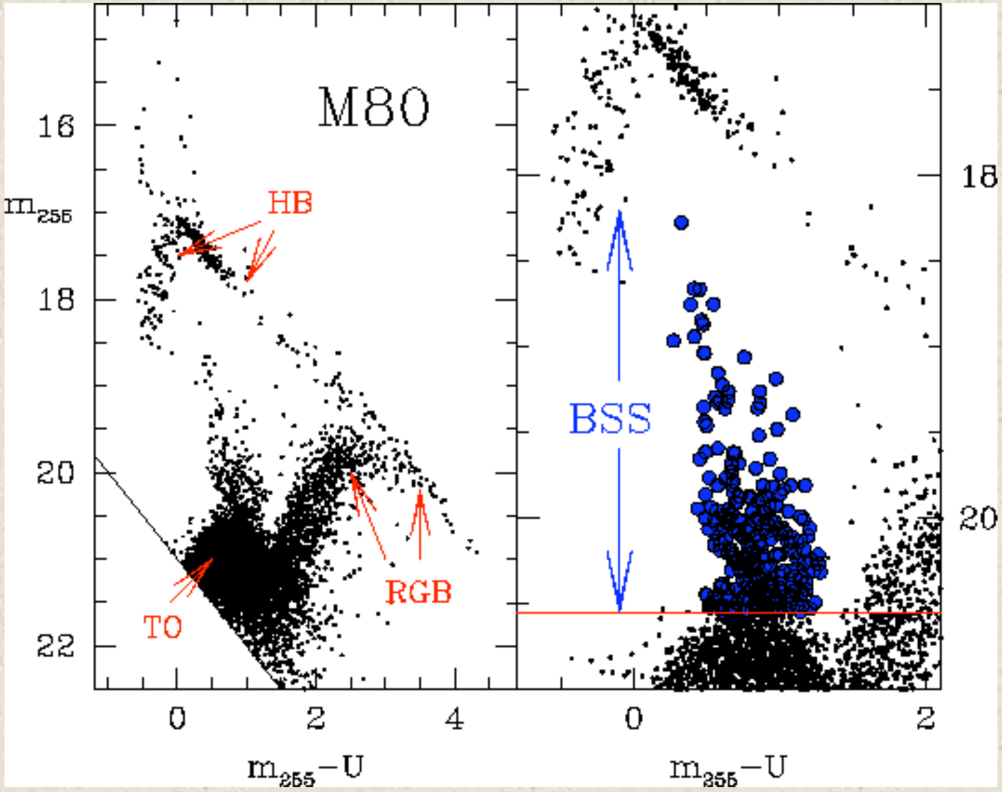
$\mathcal{F}$ = *BSS* specific frequency

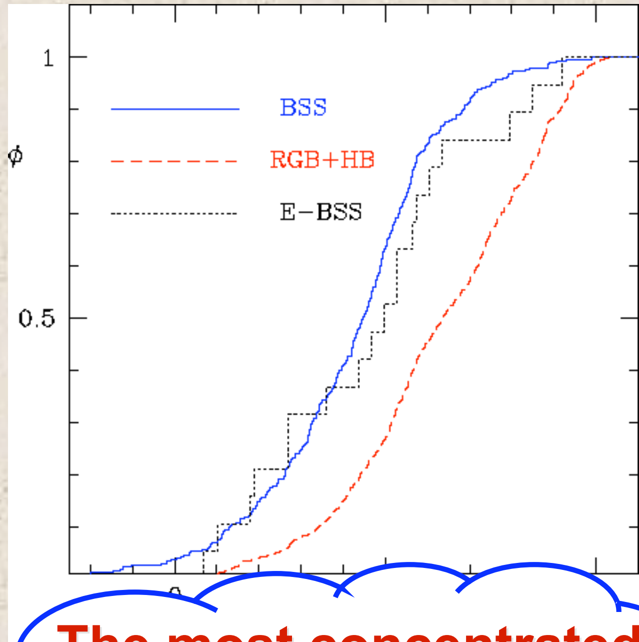
$\mathcal{F} = N_{BSS} / N_{HB}$

Cluster	$[Fe/H]$	$Log\rho_0$ $[M_\odot/pc^3]$	N_{b-BSS}	N_{HB}	F_{BSS}^{HB}
NGC5272(M3)	-1.66	3.5	72	257	0.28
NGC6205(M13)	-1.65	3.4	16	237	0.07
NGC6093(M80)	-1.64	5.4	129	288	0.44
NGC6254(M10)	-1.60	3.8	22	82	0.27
NGC288	-1.40	2.1	24	26	0.92
NGC6341(M92)	-2.24	4.4	53	159	0.33
NGC6752	-1.60	5.2	17	108	0.16

Ferraro et al (2003, ApJ, 588,464)

The large population of BSS in M80





The most concentrated **BSS** population ever found in a GGC

WHY M80 has a such large BSS pop?

Could the dynamical evolution of the cluster play a role in the formation of *BSS*?

M80 is not a PCC but its dynamical time scale is shorter than its age!!

Are collisions delaying the core collapse generating COL-BSS?

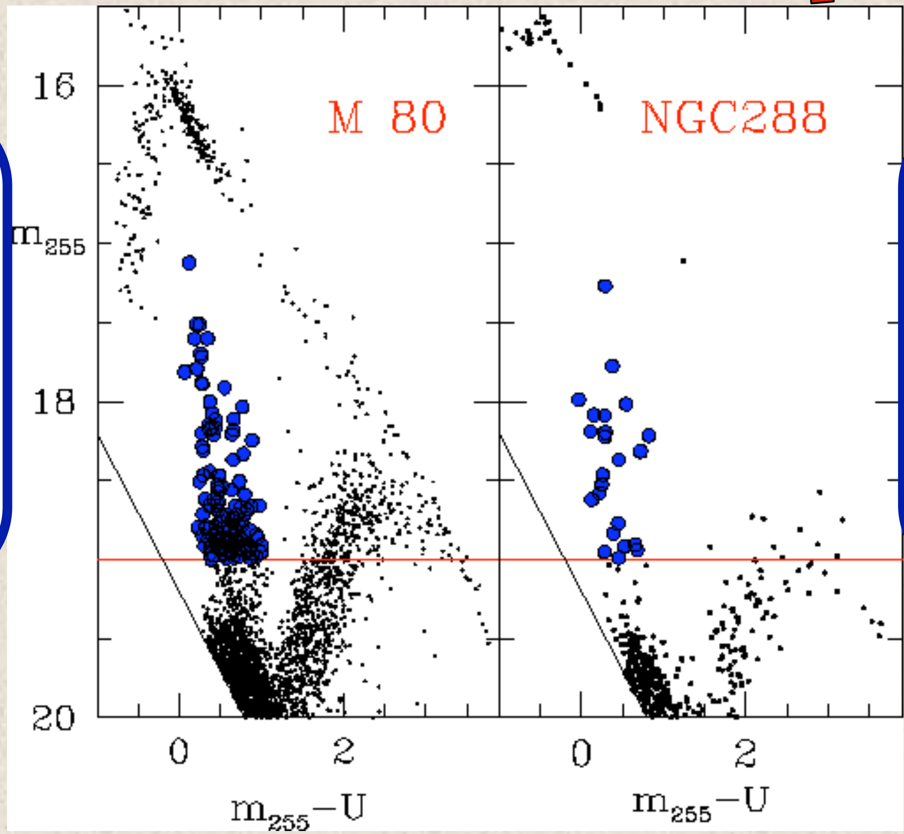
Direct comparison of BSS populations

Log ρ_0 = 5.8 M_s/pc^3

N_{BSS} = *129*

$\mathcal{F}$ = 1.00

if only the PC is considered



Log ρ_0 = 2.1 M_s/pc^3

N_{BSS} = *24*

$\mathcal{F}$ = 0.92 !!!

the largest specific frequency ever observed in one of the lowest density cluster

Different type of BSS ?

COL-BSS in M80 ⇐ **?** ⇒ **PB-BSS in NGC288**

Direct comparison of BSS populations

twin clusters

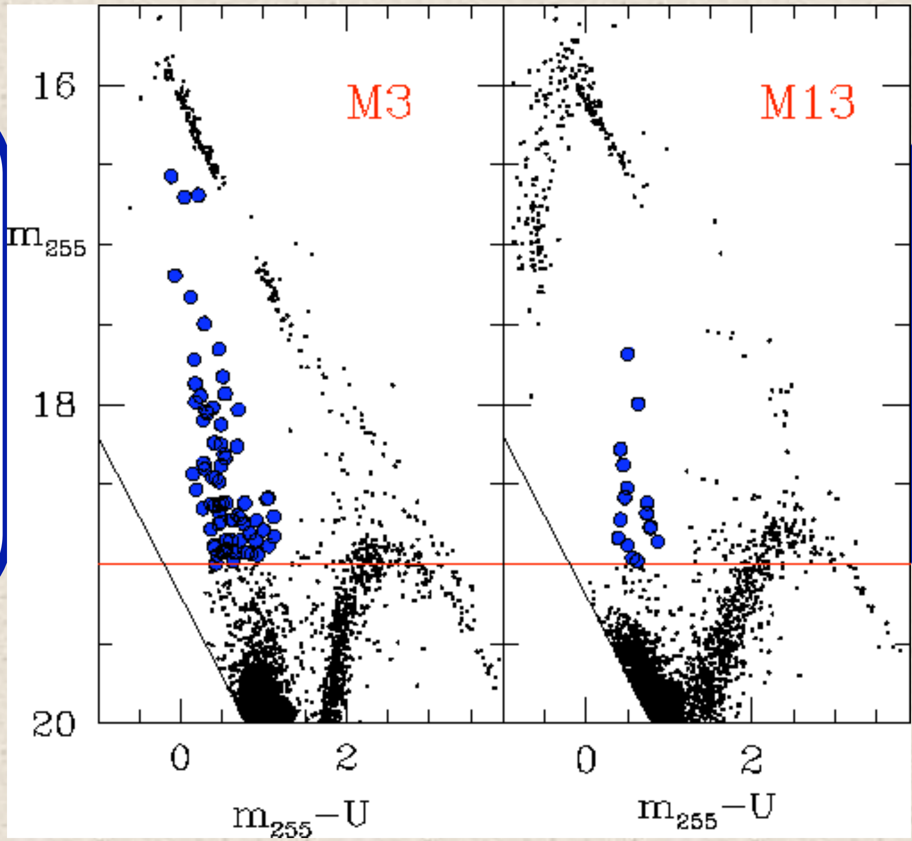
M 3

Log ρ_0 = 3.5 M_s/pc^3

Log M = 5.8 M_s

N_{BSS} = *72*

$\mathcal{F}$ = 0.28



M 13

Log ρ_0 = 3.4 M_s/pc^3

Log M = 5.8 M_s

N_{BSS} = *16*

$\mathcal{F}$ = 0.07

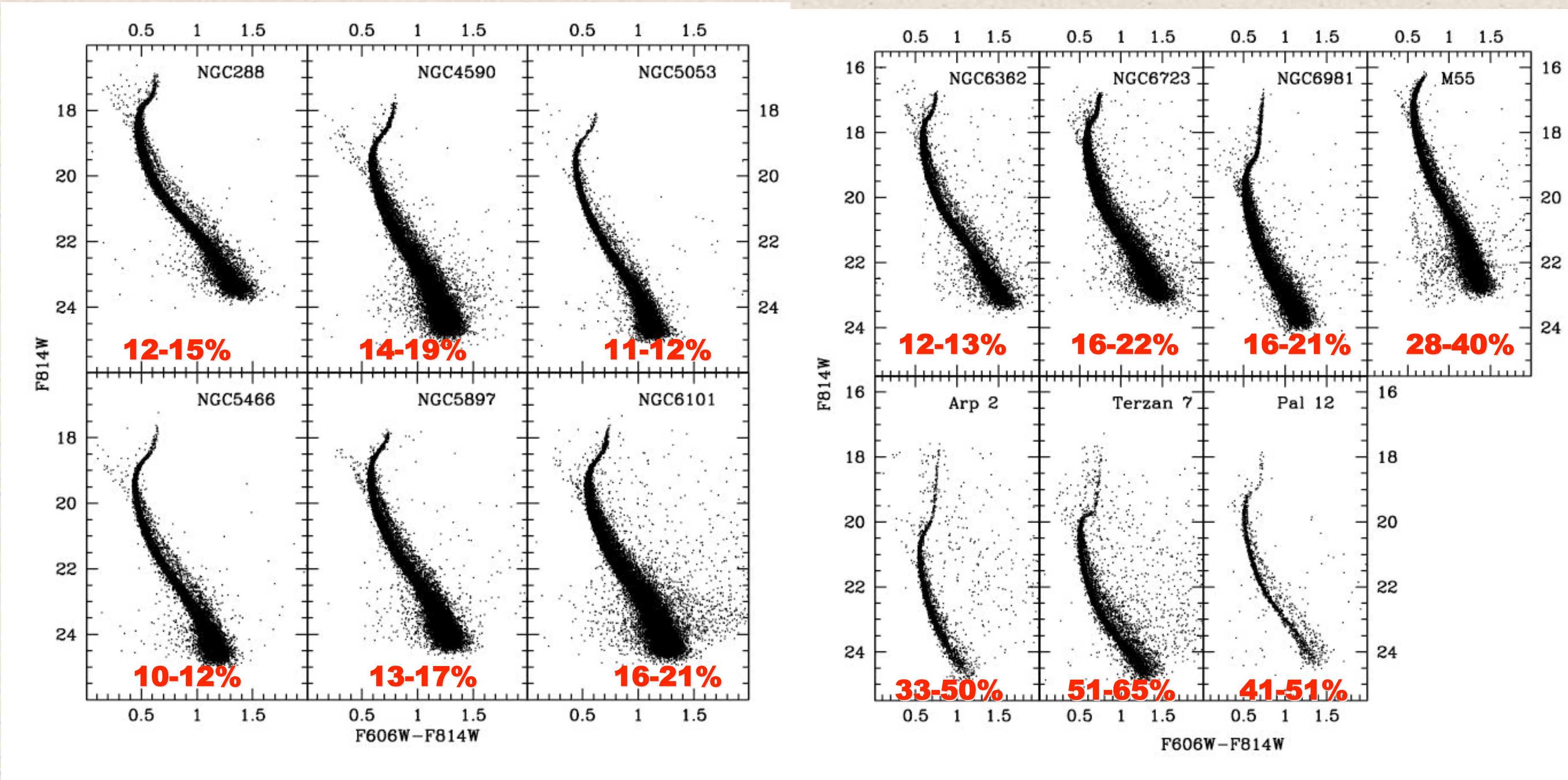
clusters in different dynamical phases ?

?

different binary content ?

Which is the binary fraction in GGCs ?

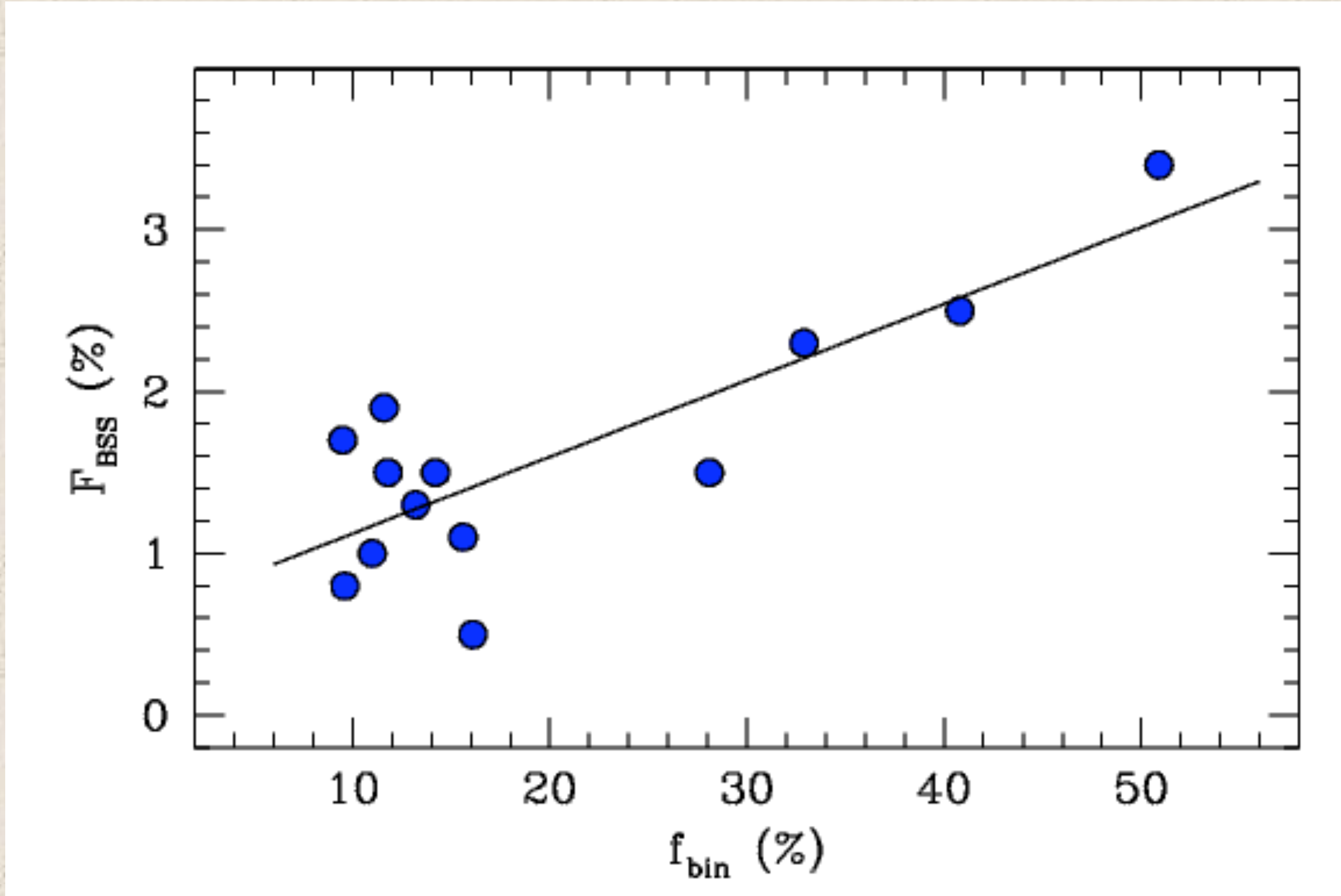
The Binary fraction in 13 low-density clusters from ACS-HST observations



Sollima et al (2007, MNRAS, 380,781)

BSS & binary fraction

A strong correlation between BSS and the binary fraction has been found in 13 low-density (Log ρ <2.5)clusters



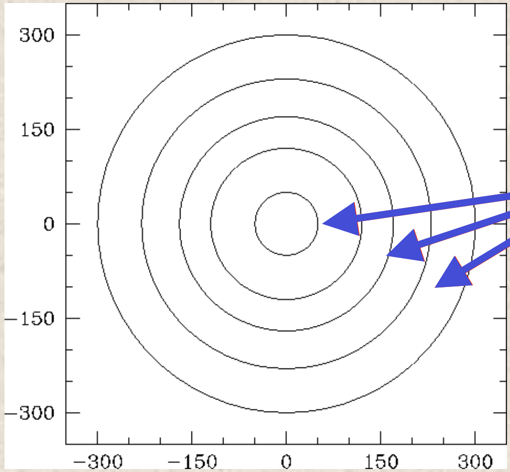
Sollima et al (2008, A&A, 481,701)

The BSS radial distribution

The population of BSS in the central region of clusters is only part of the story: in fact the global BSS radial distribution contains important signatures of the cluster dynamical evolution

BSS in M3

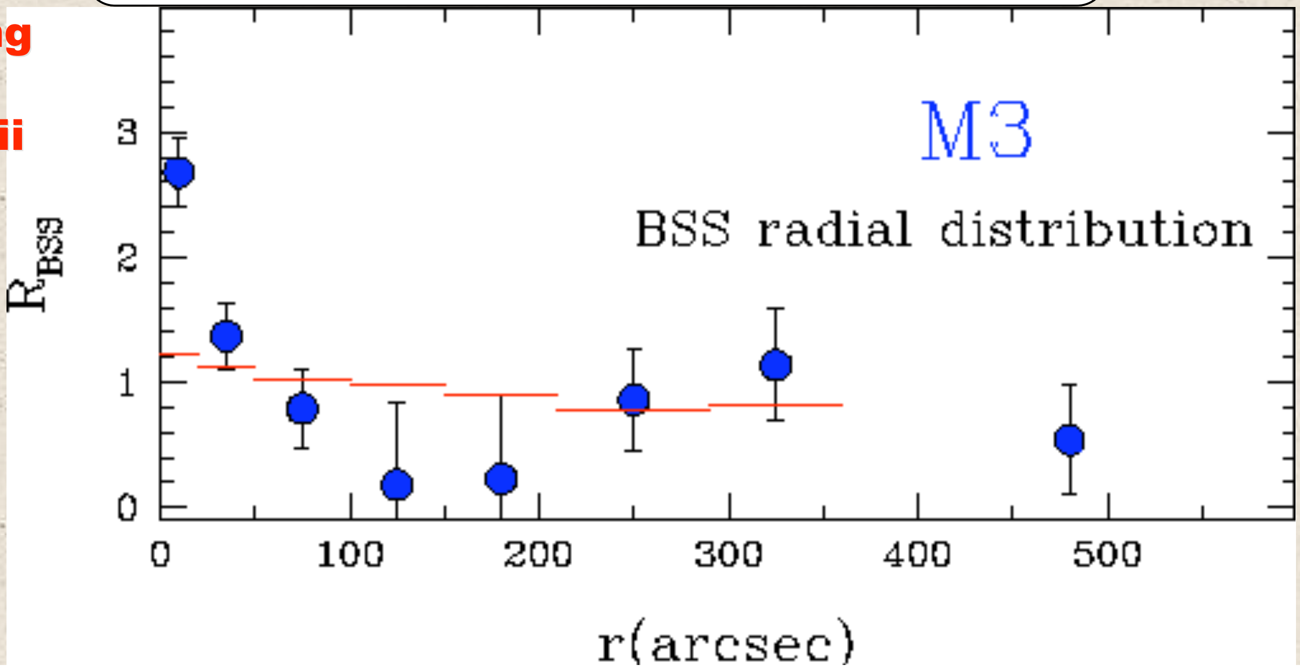
The first complete coverage of the entire cluster extension



$$R_{BSS} = \frac{N_{BSS}/N^{TOT}}{L_S/L_{TOT}}$$

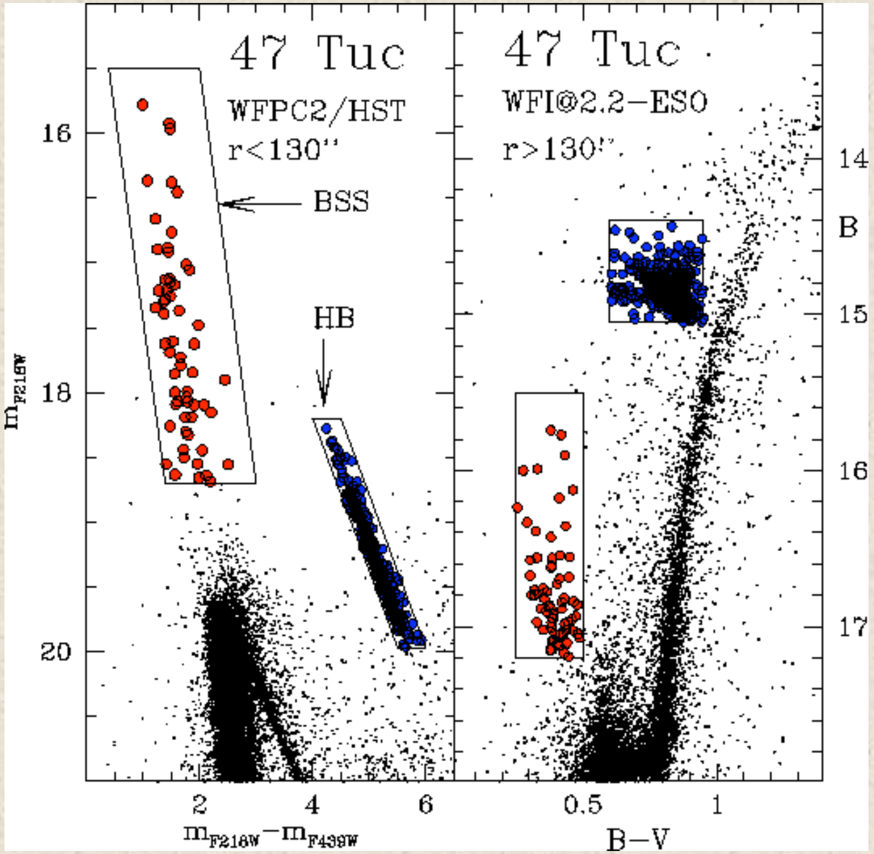
Highly peaked in the center, rapidly decreasing at intermediate radii and rising again at larger radii

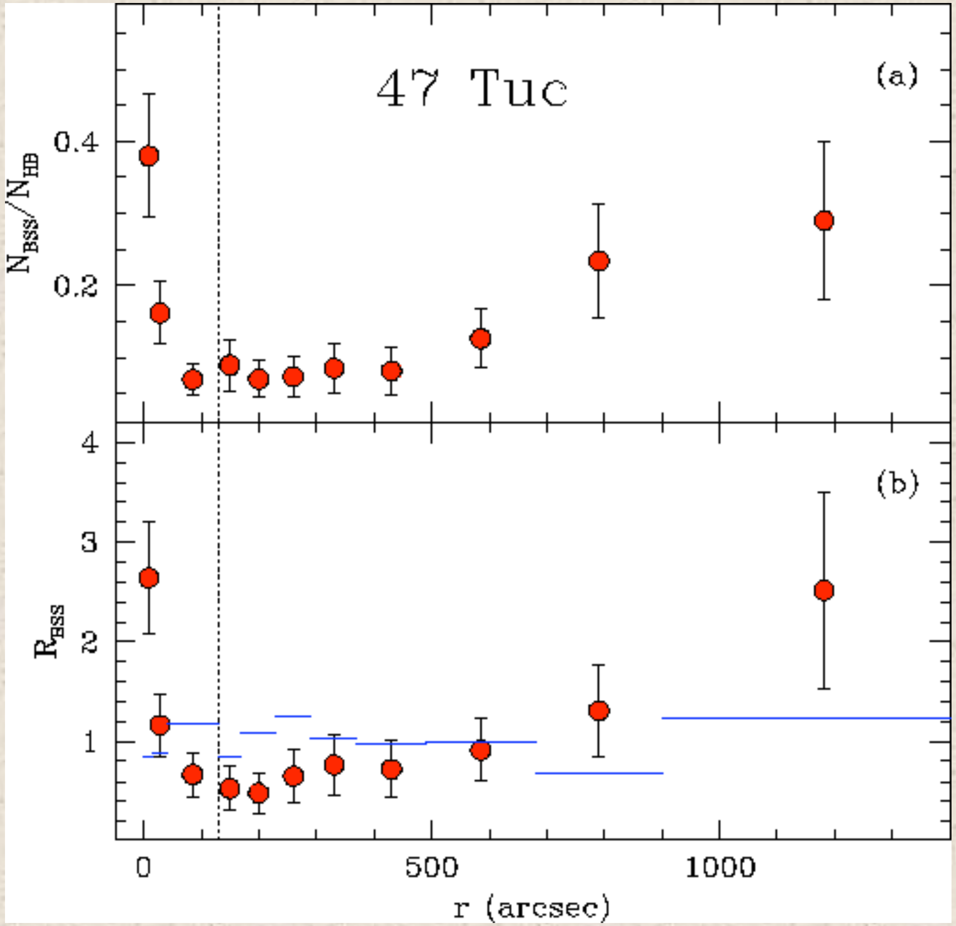
The BSS radial distribution is BIMODAL



Is this distribution really "peculiar" & unique ?

BSS radial distribution: 47 Tuc

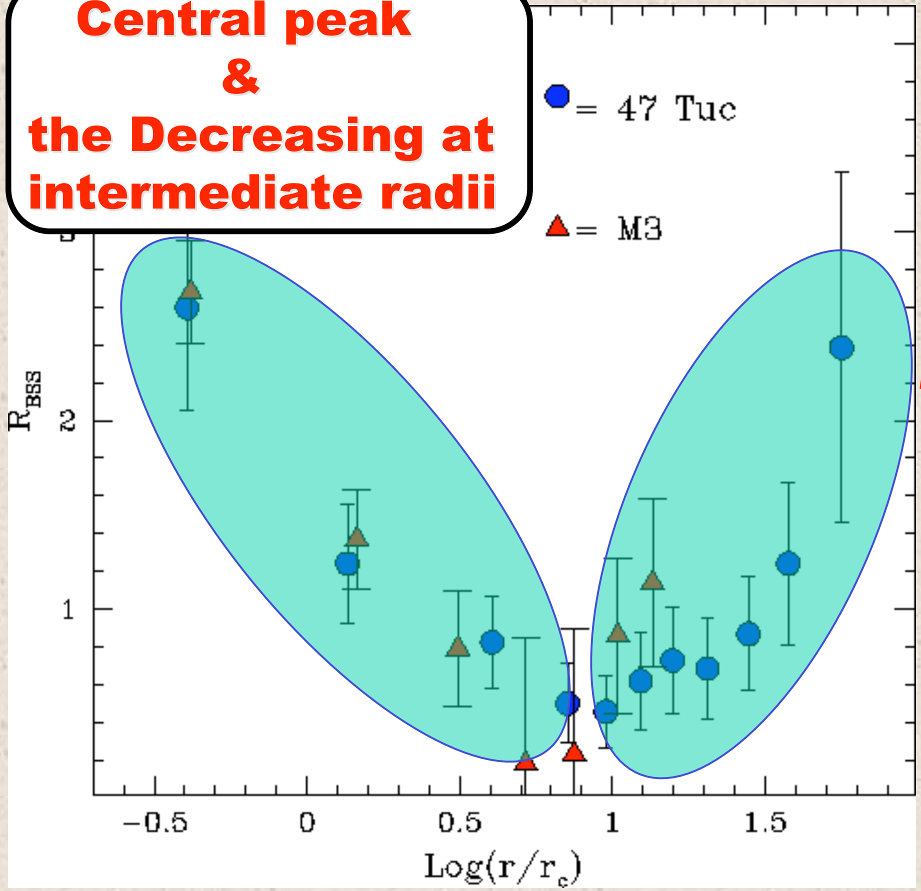




The BSS radial distribution in 47 Tuc is quite similar to that observed in M3

The BSS bimodal distributions

Central peak
&
the Decreasing at intermediate radii



the Rising branch at large radii

?

~~COL-BSS kicked off from the cluster core~~

or

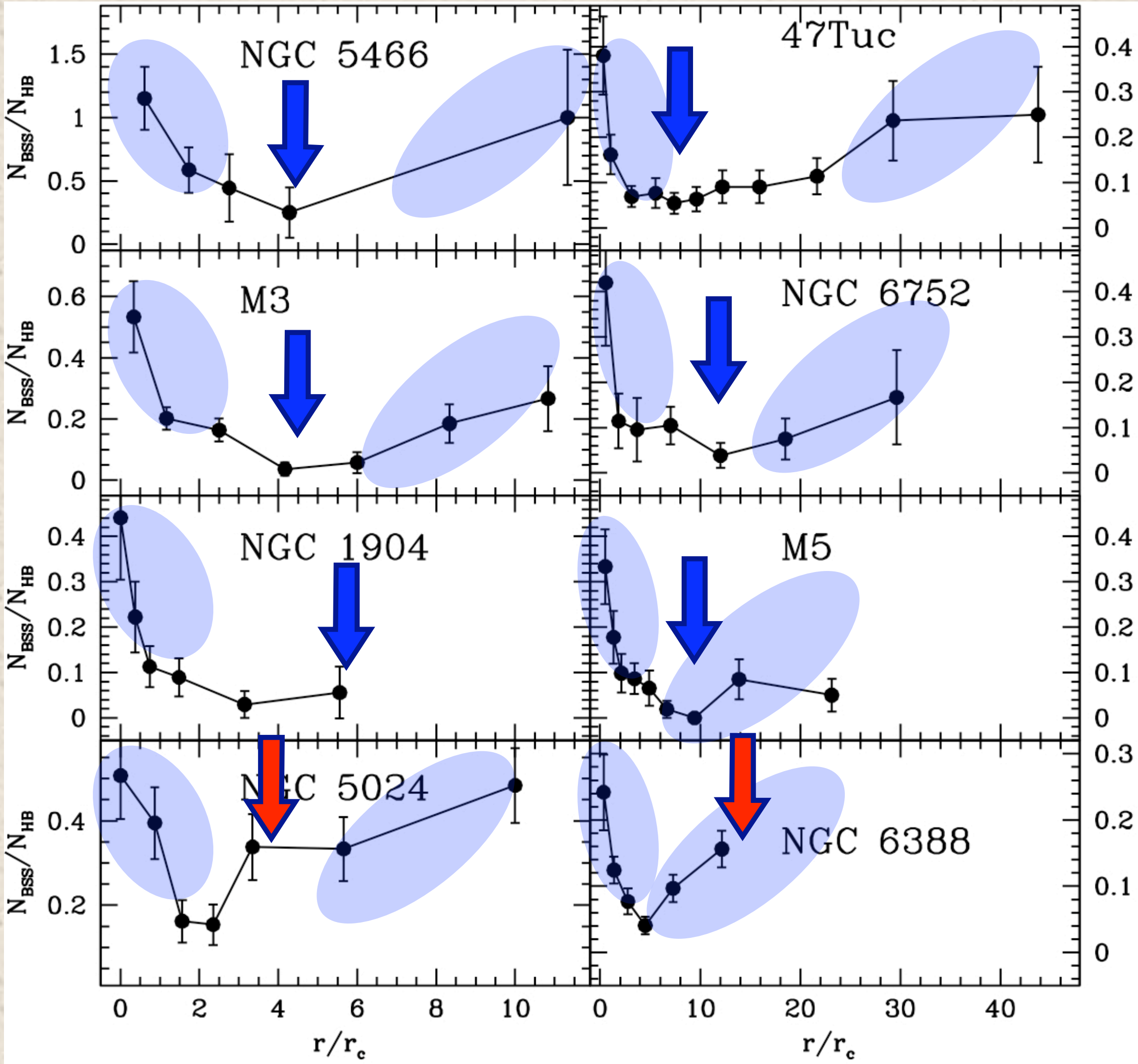
BSS generated by primordial binaries

Dynamical simulations (Mapelli et al 2006, Lanzoni et al 2007) showed that a pop. of PB-BSS is needed to reproduce the bimodal distribution

COL-BSS +PB-BSS sunk into the core by mass segregation & dynamical friction

COL-BSS+PB-BSS @ center & PB-BSS in the outer regions?

BSS radial distributions

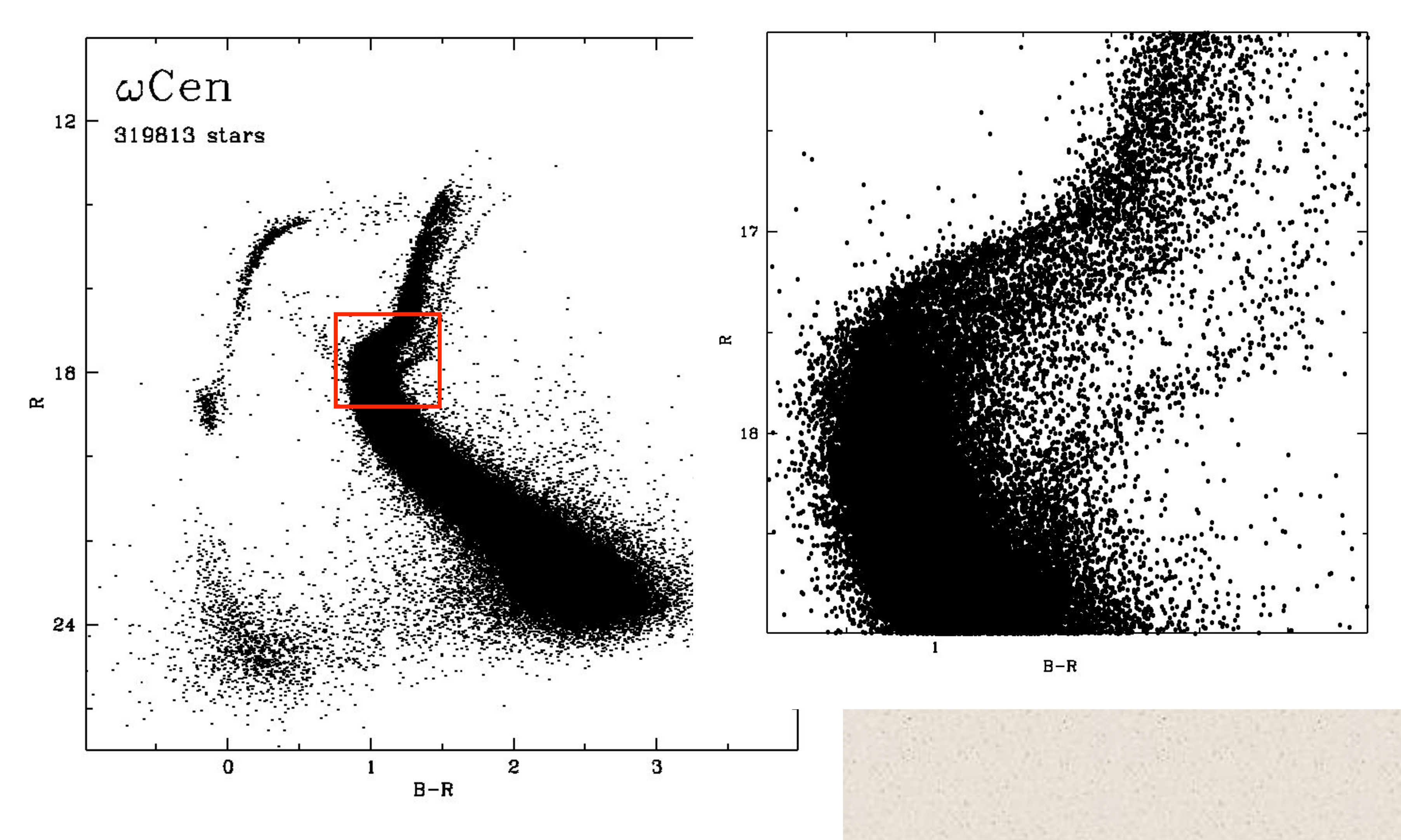


Minimum of rad distr.
=
Radius of avoidance

Radius at which all objects with a mass similar to BSS have been sunk into the core (because of the dynamical friction) in a time comparable to the cluster age

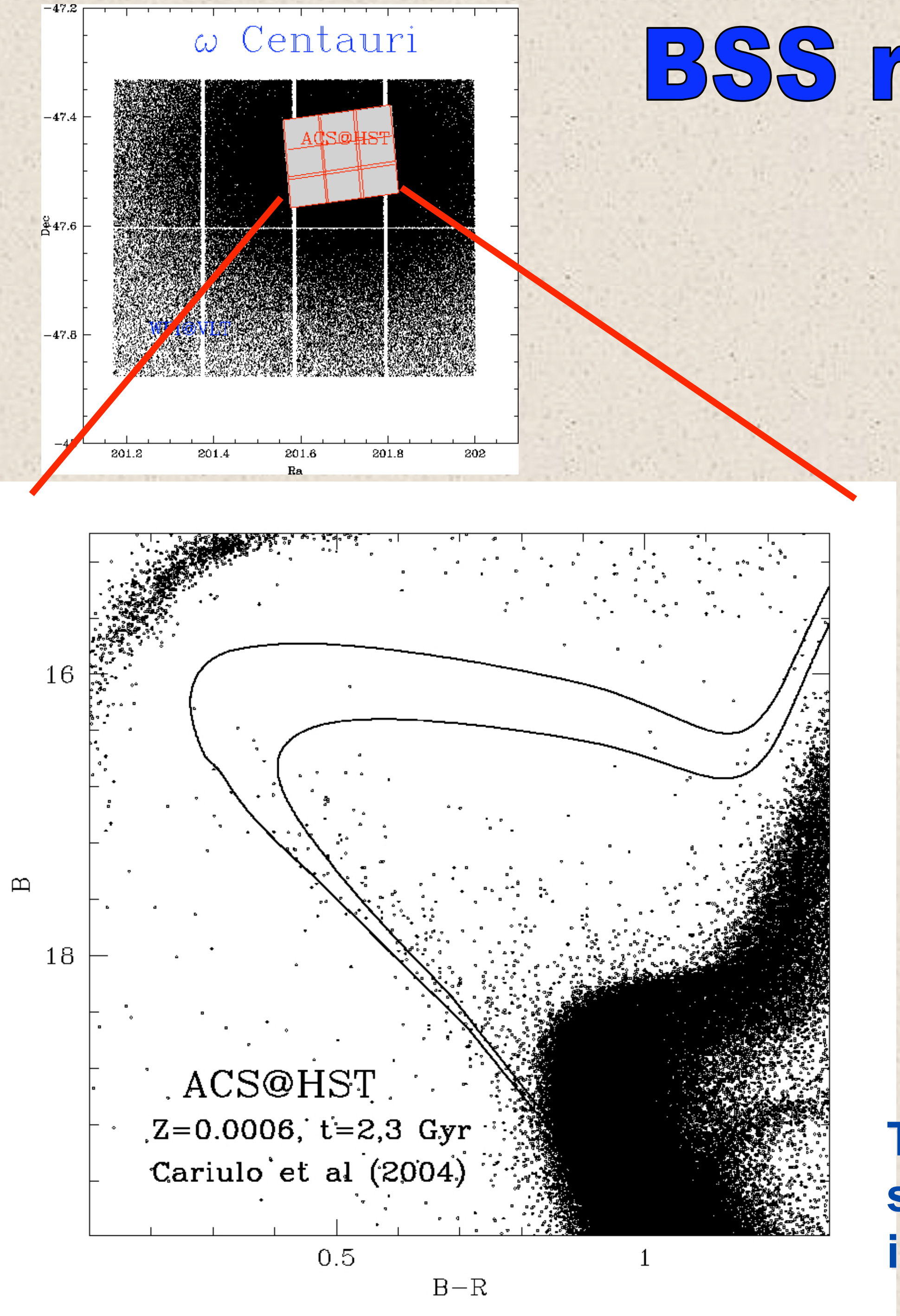
Important signatures of the dynamical evolution of the parent cluster are imprinted in the BSS properties

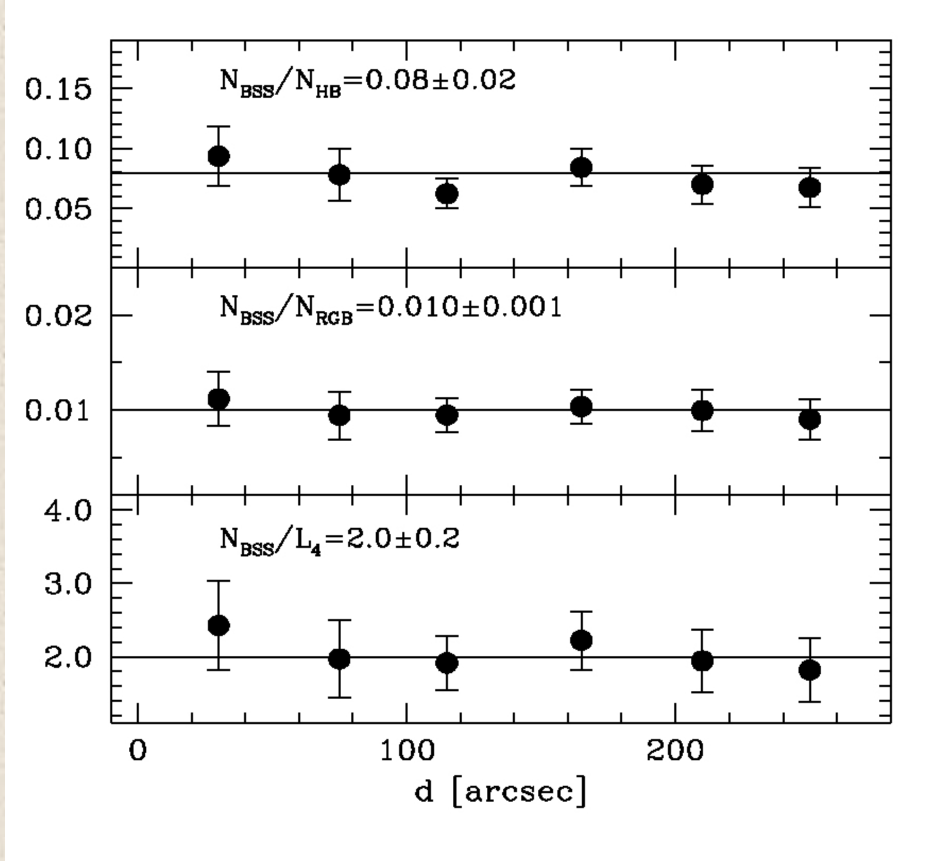
Omega Centauri



Ferraro et al. (2004, ApJ, 603,L81)

BSS radial distribution

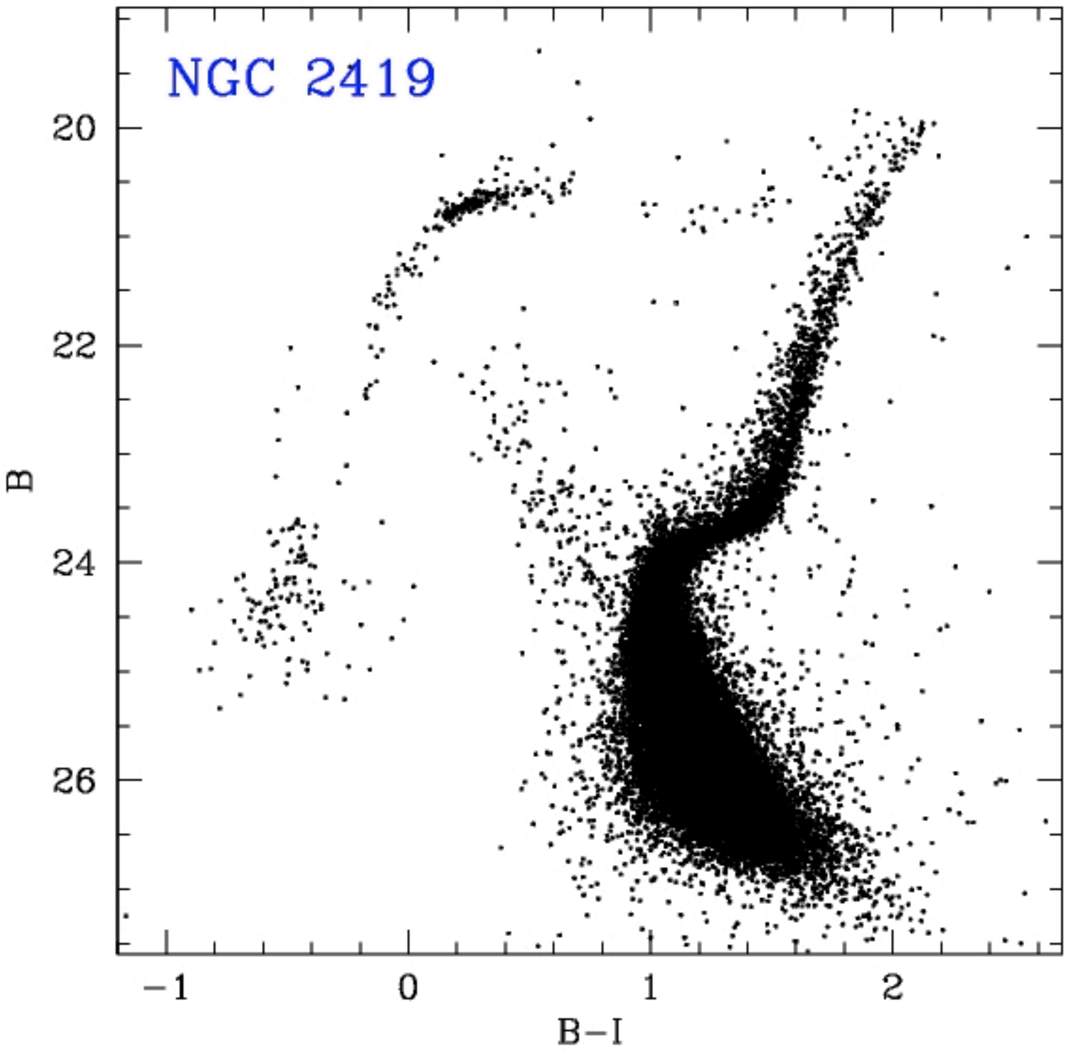


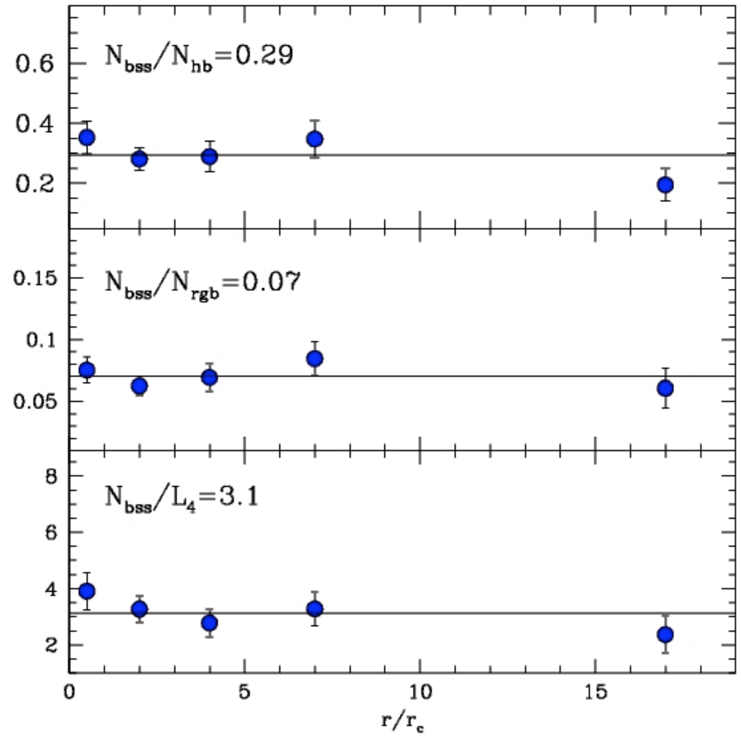


ϖ Centauri: NO evidence of mass segregation!!!!

This is the cleanest evidence that the system is not completely relaxed even in the central region.

NGC2419: the BSS radial distribution





NGC2419: No evidence of mass segregation!!!!

How can we distinguish COL-BSS & PB-BSS?

Dalessandro et al (2008, ApJ,681,311)

Searching for chemical signatures of the BSS formation process

High-resolution (R=11700) spectroscopy of BSS with UVES and MEDUSA @ESO-VLT

Ferraro, Lanzoni, Gratton, Piotto,Mucciarelli, Fusi Pecci, Beccari, Lucatello, Rood, Sills...

C abundance from CI line at λ=9111.8 A

O abundance from OI line at λ=7774 A

GC	Log ρ	[Fe/H]
47 Tuc	5.1	-0.7
NGC 288	2.1	-1.1
NGC 6397	PCC	-1.8
M4	4.1	-1.2
NGC6752	?	-1.6
Omega Cen	1.3	-1.6

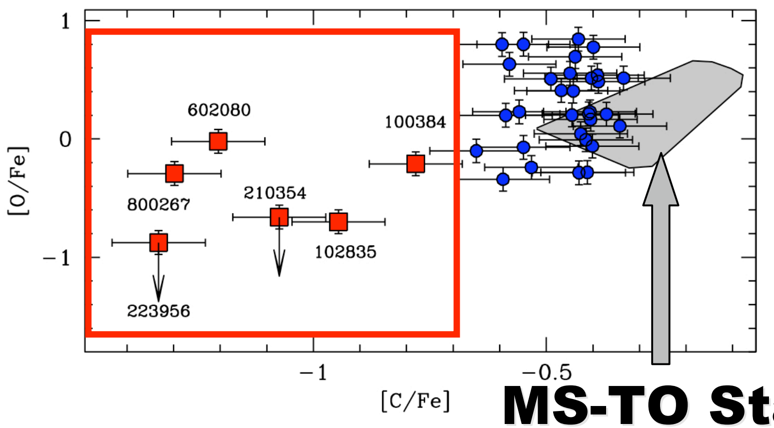
2 successfull runs at the VLT with FLAMES allowed us to collect data for ~ 300 BSS

47 Tuc: First Results

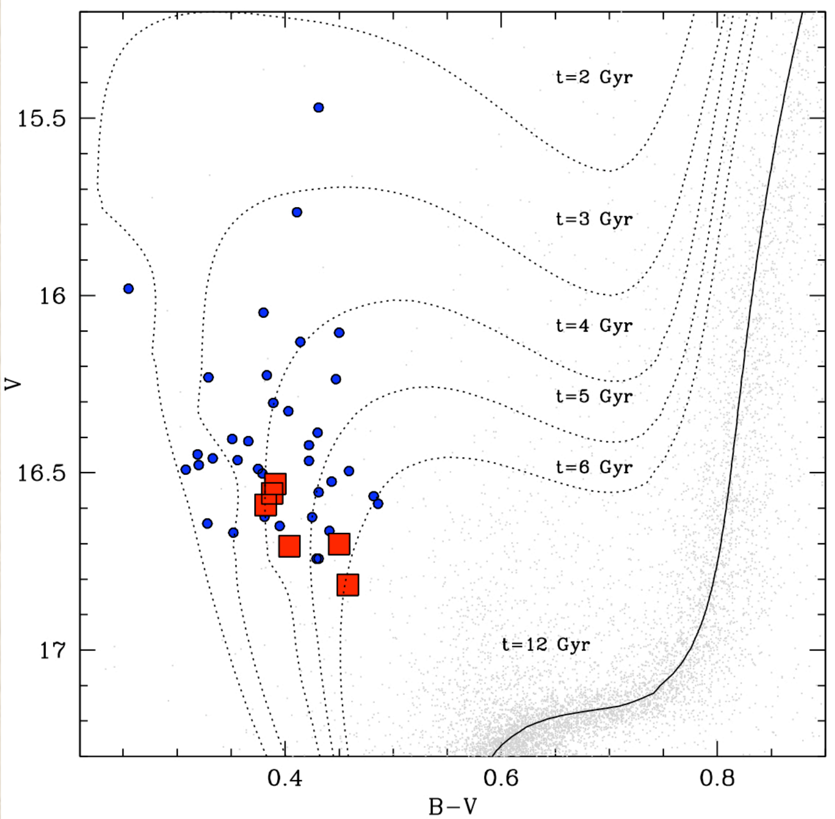
Ferraro et al 2006, ApJ,647,L56

43 BSS selected over the entire cluster extention

A sub-population of CO-depleted BSS



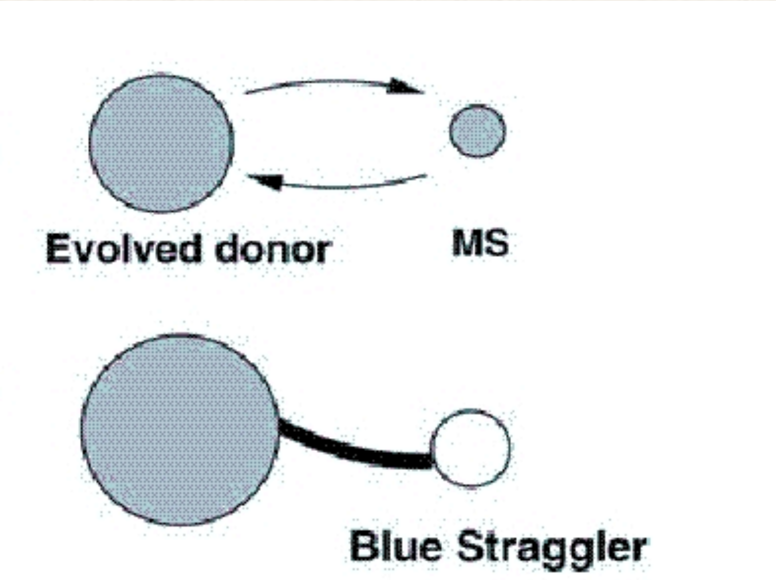
MS-TO Stars
(Carretta et al 2005)



CNO burning products on the BSS surface coming from a deeply peeled parent star as expected in the case of mass-transfer process.

The chemical signature of the PB-BSS formation process?

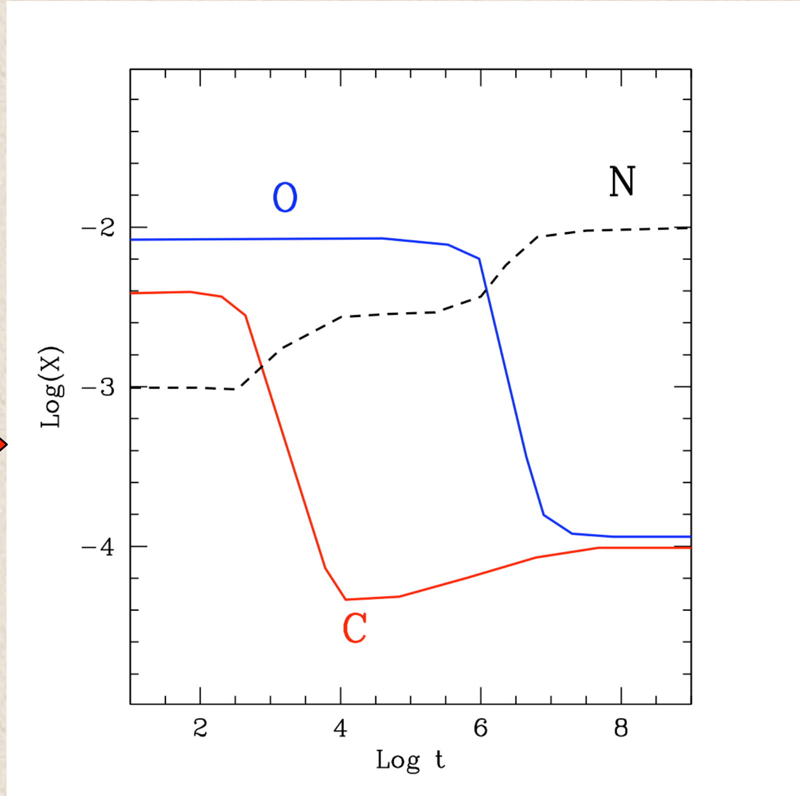
Forming a BSS through mass transfer



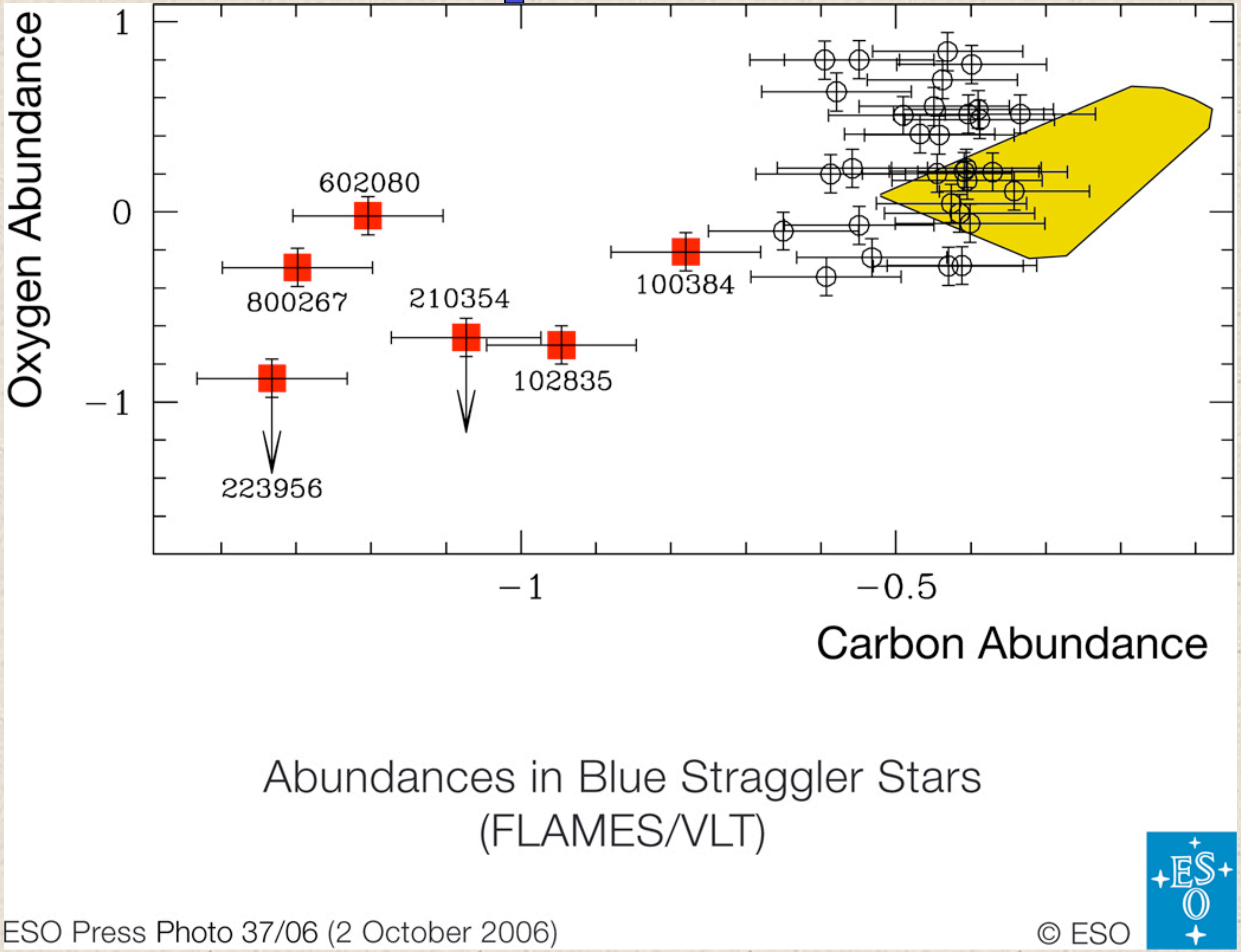
McCrea (1964)

In the scenario in which a BSS is generated by mass transfer we can expect to see the "inner" material of the donor star on the BSS surface

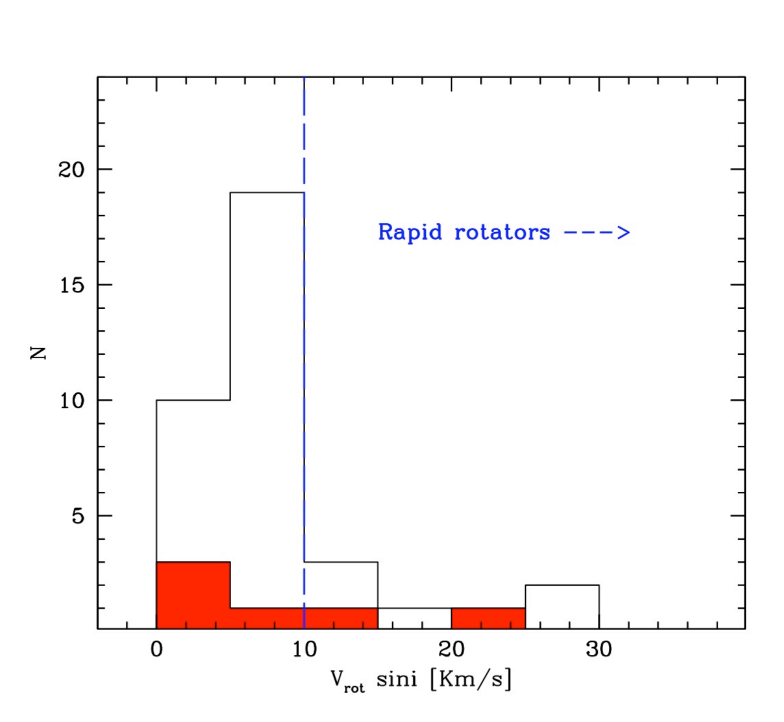
CNO processing

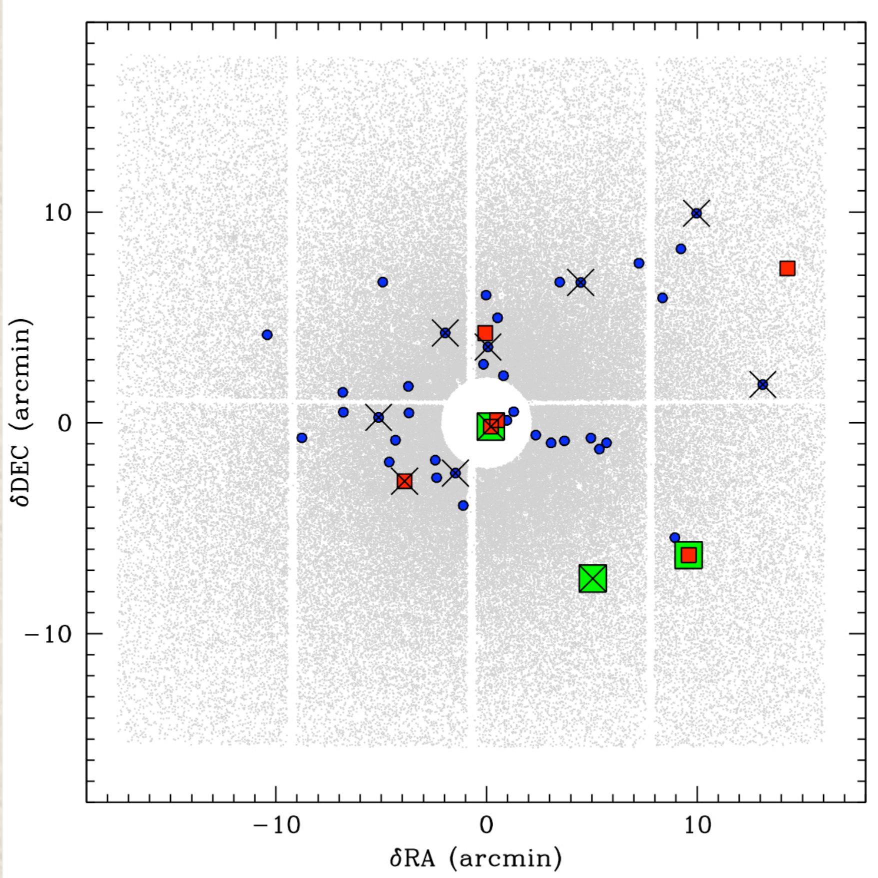


Stellar vampires unmasked



Most BSS are slow rotators





6 C,O depleted (■)

10 "moderate" rotators (X)

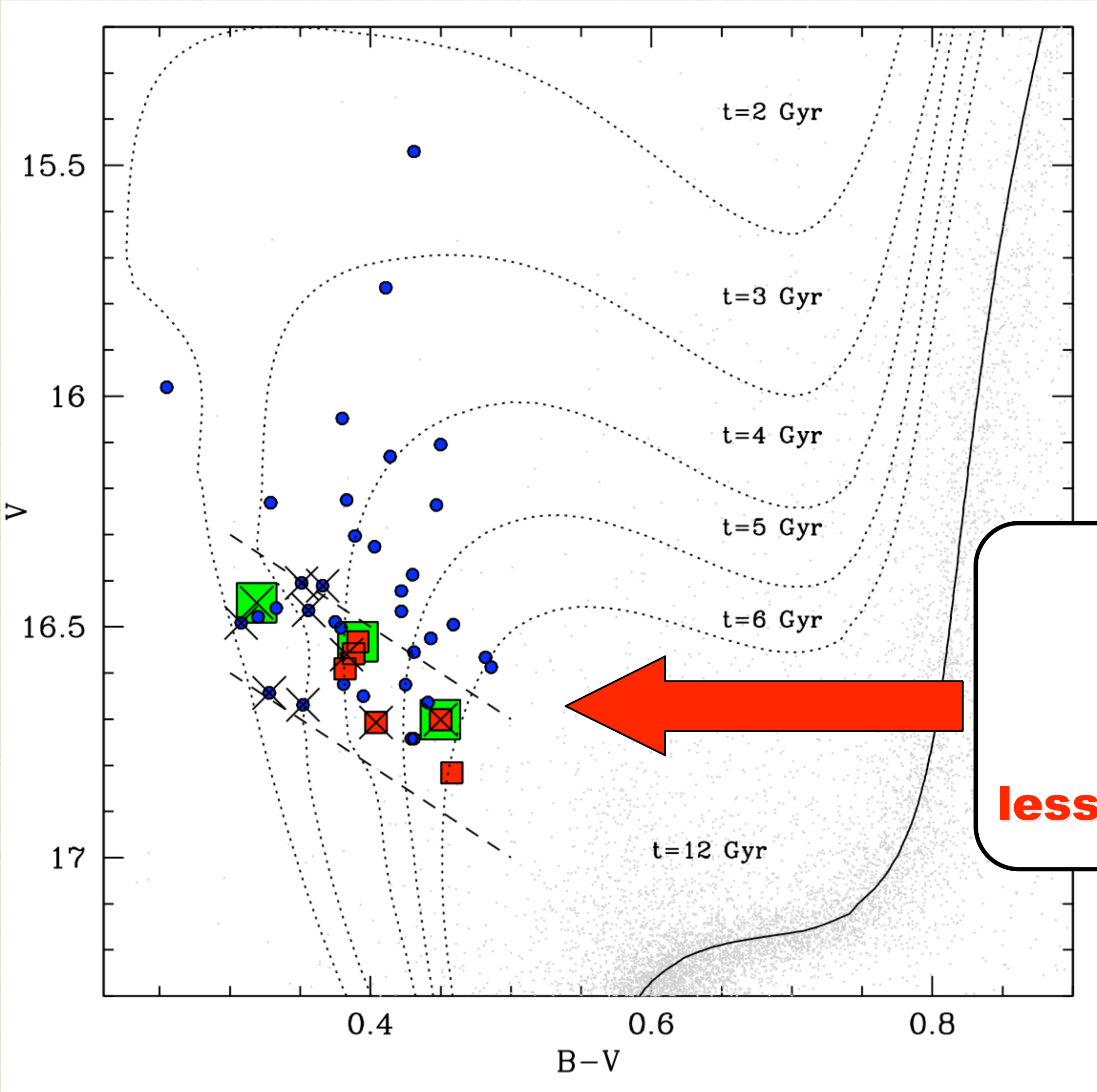
3 W Uma systems (■)

(shrinking binary systems which will finally merge into a single star – Vilhu 1982)

No significative radial segregation

(curiously the most rapid rotators are located in the outer region of the cluster)

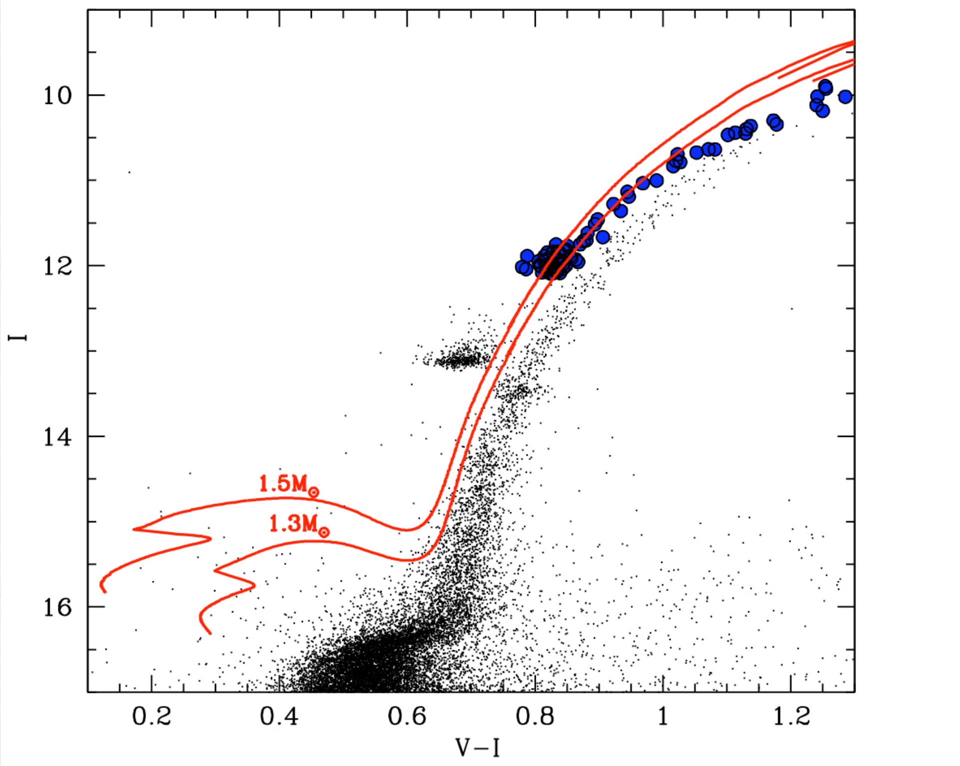
47 Tuc: First Results



CO depleted BSS
Moderate rotators
W Uma systems
all appear to be
less evolved than normal BSS

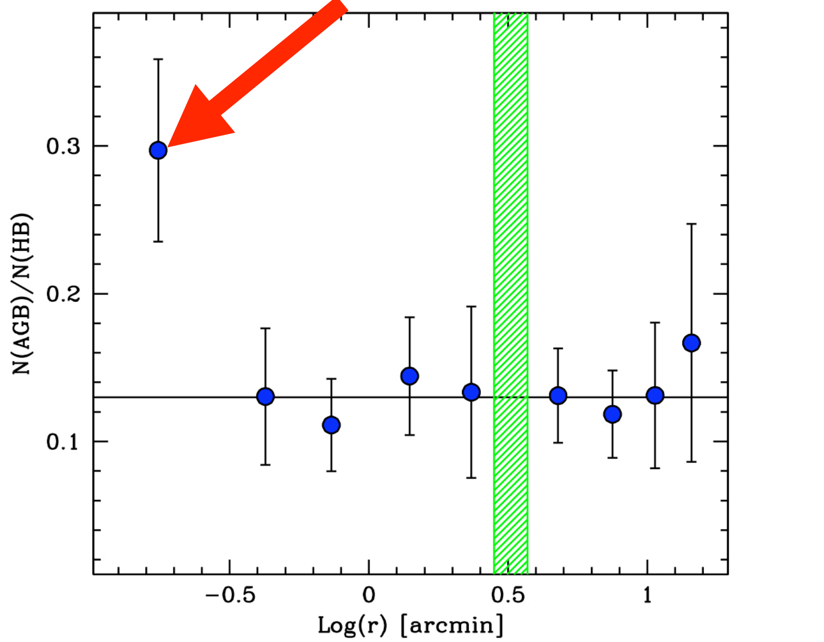
Is the CO depletion stage "transient" ?
Can mixing process "clean-up" (mitigate) the chemical anomaly ?

Evolved BSS in the AGB of 47 Tuc?



Beccari et al (2006), ApJ, 652, L121

Contamination by non genuine low-mass AGB ???



Pay attention to the E-BSS contamination of the "canonical" evolutionary sequences !!!

CONCLUSIONS

The Exploration of “exotic” stellar populations in GGCs has just begun

Important signatures of the dynamical evolution of the parent cluster are imprinted in the properties of BSS

Photometric and spectroscopic studies of BSS are opening a new window on the formation and evolution processes of exotic objects in high density enviroments


The End