BSS as probe-particles of cluster internal dynamics: an observational prospective

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Cosmic-Lab

- 5-year project
- *Advanced Research Grant* funded by the European Research Council (ERC)
- PI: Francesco R. Ferraro (Dip. of Physics & Astronomy – Bologna University)
- AIM: **to understand the complex interplay between dynamics & stellar evolution**
- HOW: using **globular clusters** as cosmic laboratories and

Blue Straggler Stars
Millisecond Pulsars
Intermediate-mass Black Holes
} as probe-particles

Globular clusters: cosmic laboratories?

ASTRO - ARCHEOLOGY

TRACERS
of the structure & history
of the Galaxy

ASTRO - TIMING

LABORATORY
for theoretical models
of stellar evolution

ASTRO - DYNAMICS

LABORATORY
environment → SE

Simple Stellar Populations… ?

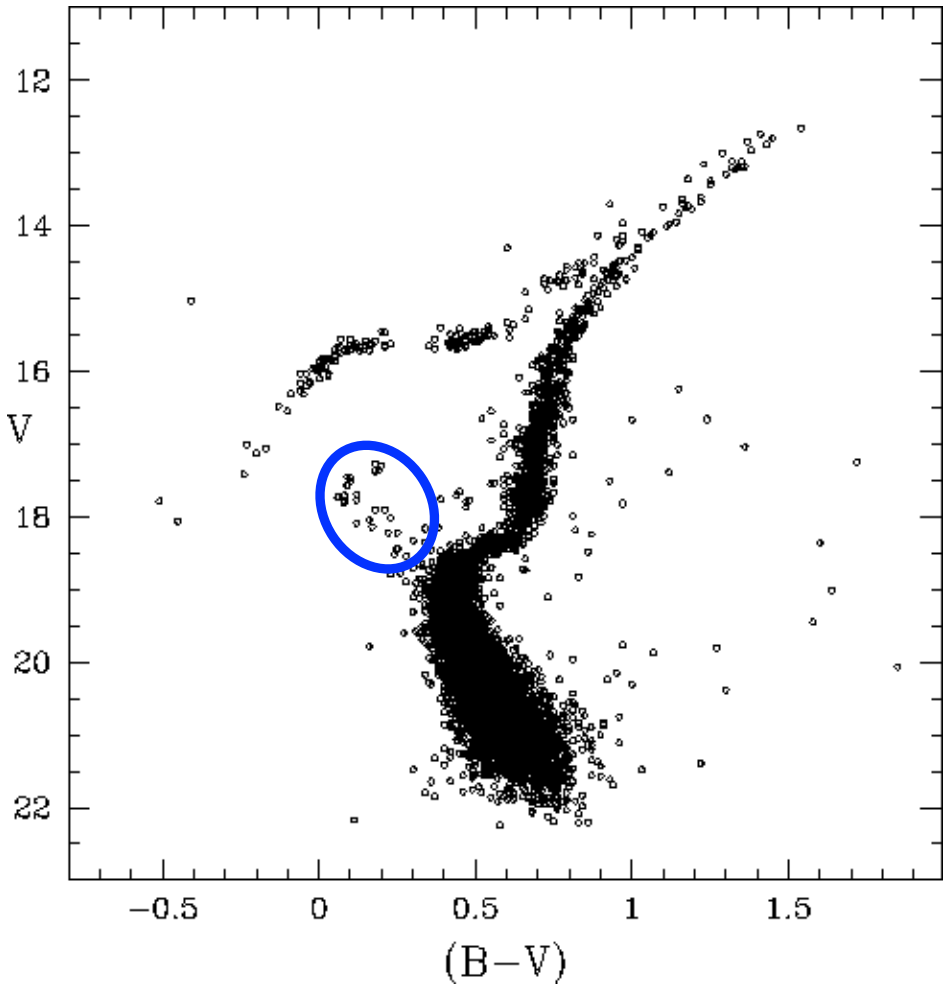
A "Simple Stellar Population" (SSP) is an assembly of stars ….

1) with the same age
(only one formation burst)

2) with the same initial chemical composition

3) single (not located in binary systems)

Simple Stellar Populations… ?



Binaries are there!!!
This is known since 1953

Simple Stellar Populations… ?

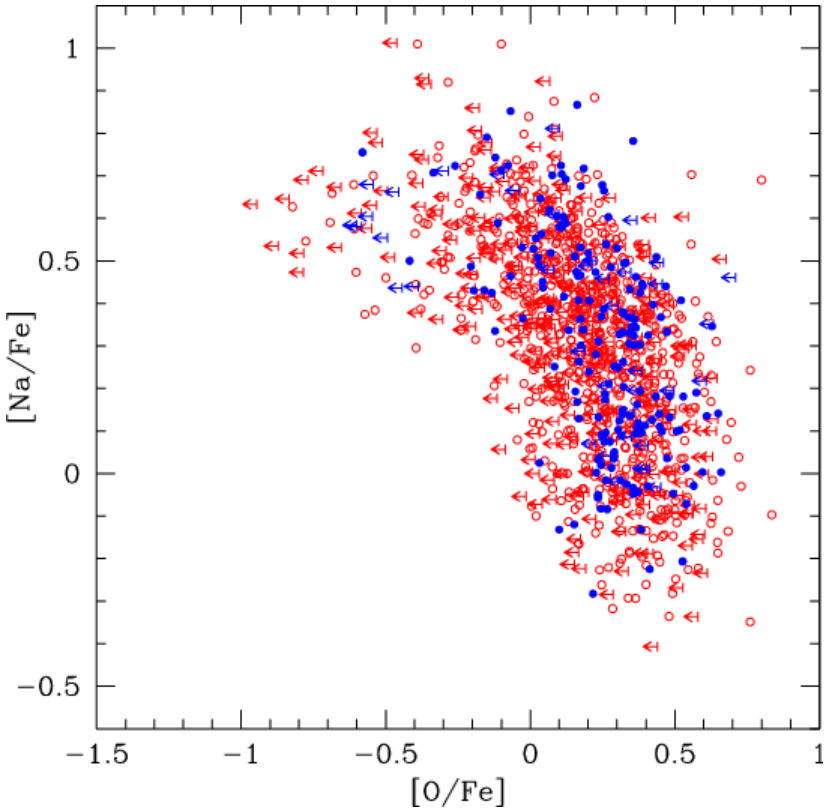
A "Simple Stellar Population" (SSP) is an assembly of stars ….

1) with the same age
(only one formation burst)

2) with the same initial chemical composition

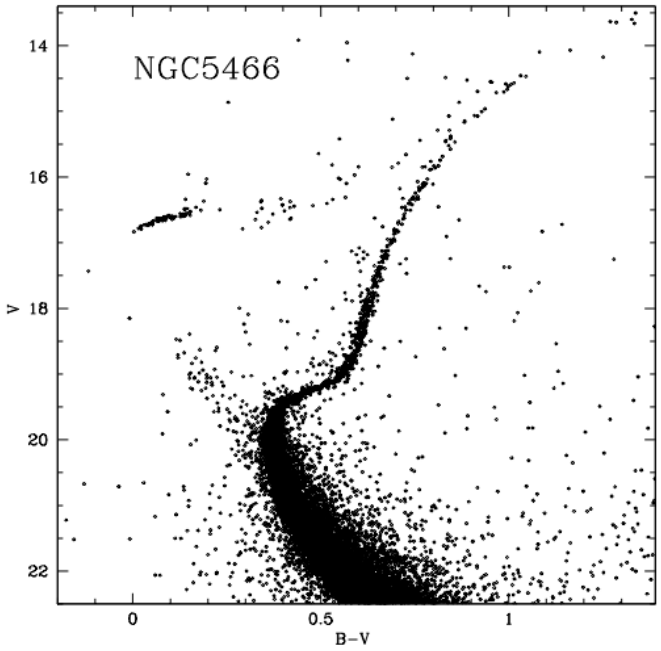
3) single (not located in binary systems)

STARS IN GGCs ARE NOT CHEMICALLY HOMOGENEOUS IN LIGHT ELEMENTS



Cumulative behaviour of [Na/Fe] as a function of [O/Fe] for 19 GGCs (Carretta et al. 2009)

BUT Stars are QUITE homogeneous in the IRON content



..with only 2 major (Δ[Fe/H]>0.5 dex) exceptions:

Omega Cen in the Halo

Terzan 5 in the Bulge

Simple Stellar Populations… ?

A "Simple Stellar Population" (SSP) is an assembly of stars ….

1) with the same age
(only one formation burst)

Timescale is as short as a few 10^8 yr

2) with the same initial chemical composition

3) single (not located in binary systems)

Simple Stellar Populations… ?

If the question is
"Are GGCs strictly speaking SSP?"

The answer is NO, but they have NEVER been considered so

Simple Stellar Populations… ?

If the question is

"Are GGCs the simplest SP available in the Universe"

The answer is still YES, whatever complex their formation scenario is

Globular clusters: cosmic laboratories?

YES THEY ARE

ASTRO - ARCHEOLOGY

TRACERS
of the structure & history
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ASTRO - TIMING

LABORATORY
for theoretical models
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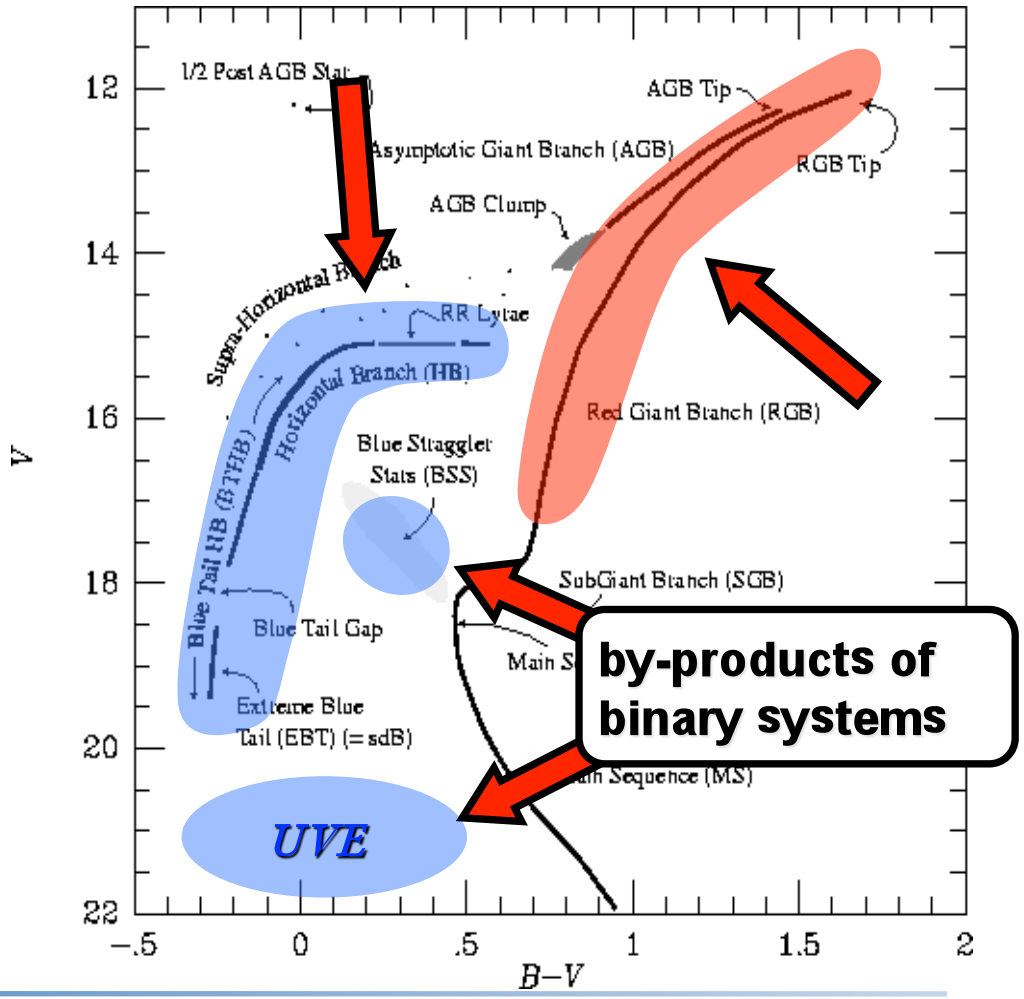
ASTRO - DYNAMICS

LABORATORY
environment → SE

Exotic populations in the CMD

ANOMALOUS sequences as Blue Stragglers Stars and UVE

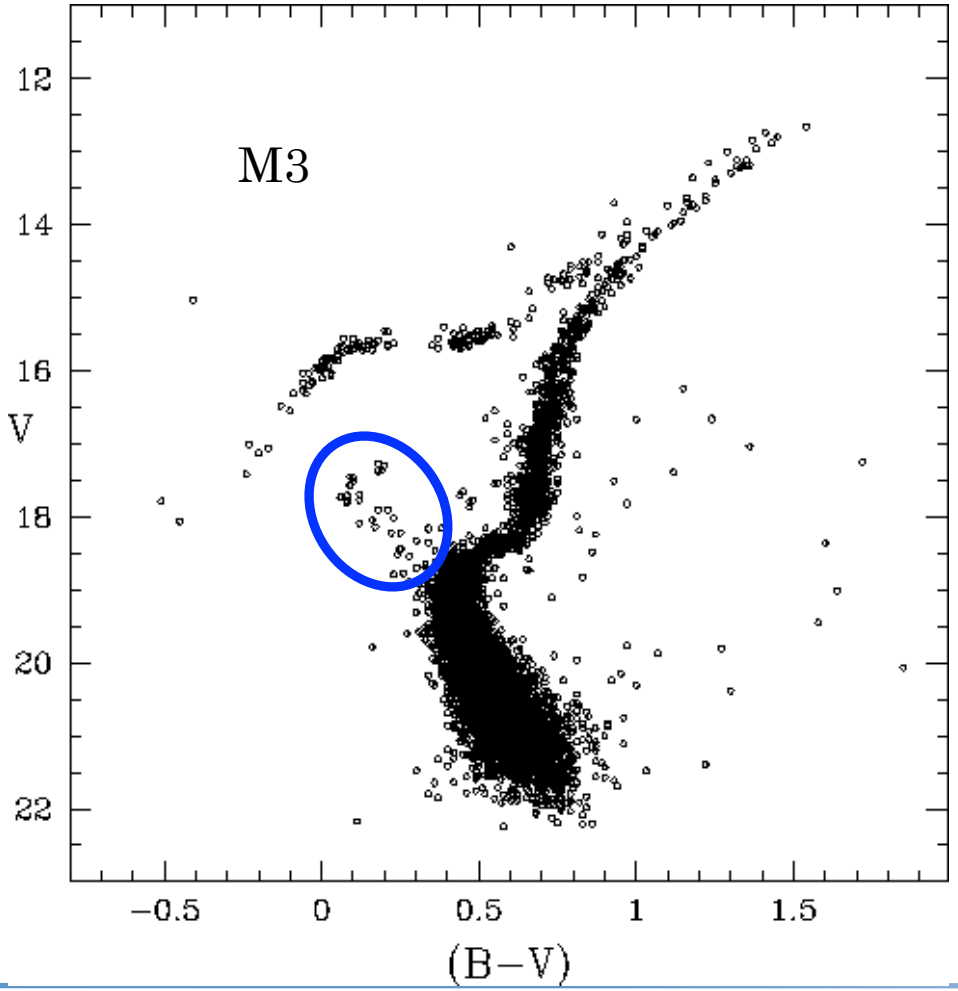
"perturbations" of "canonical" evolutionary sequences



by-products of binary systems

Blue Straggler Stars (BSS)

stars brighter and bluer (hotter) than the cluster MS-TO, along an extension of the main sequence



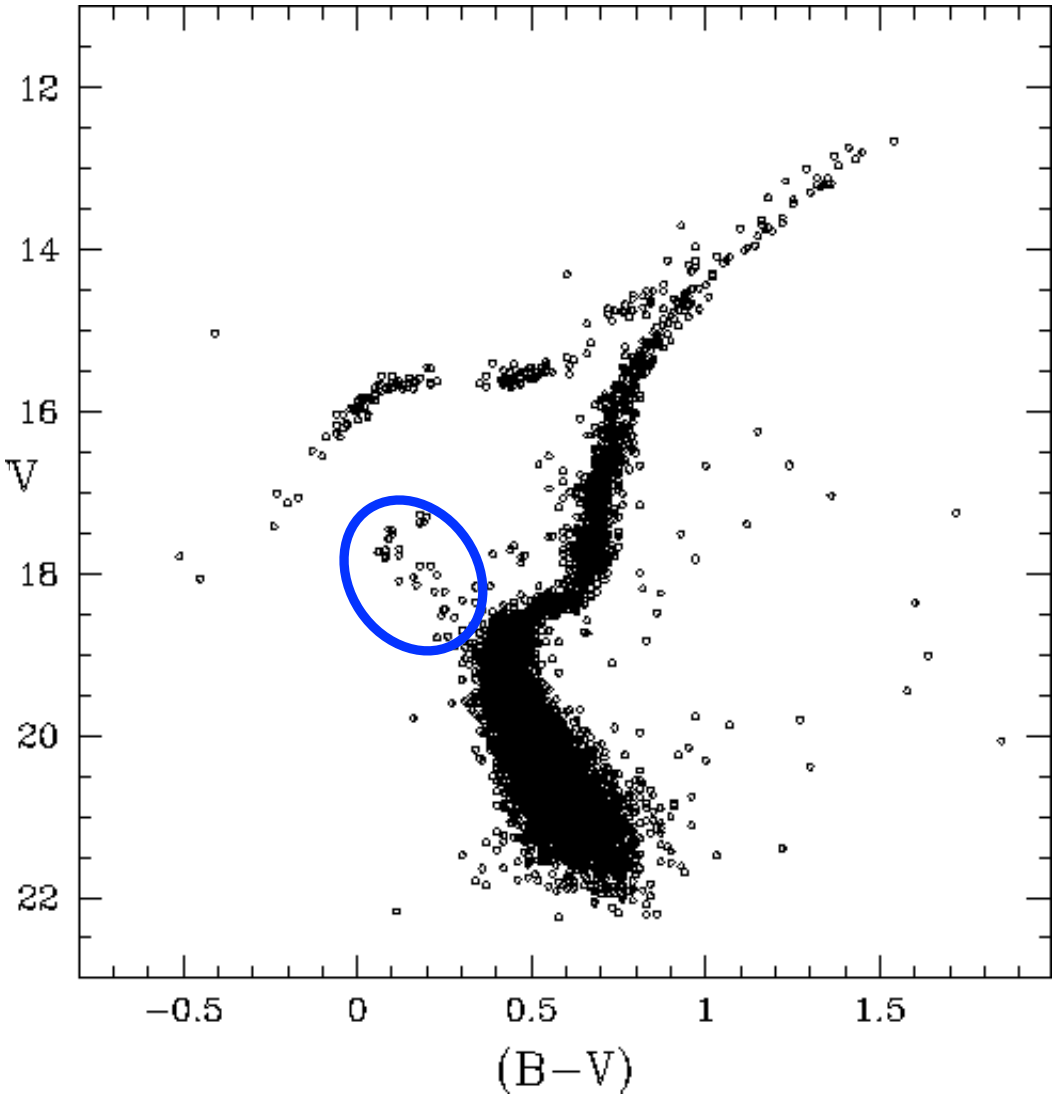
hence, they look younger !

First detected by Sandage (1953) in M3

Blue Straggler Stars (BSS)

like seeing a bunch of young vigorous folks in a meeting of old tired people..

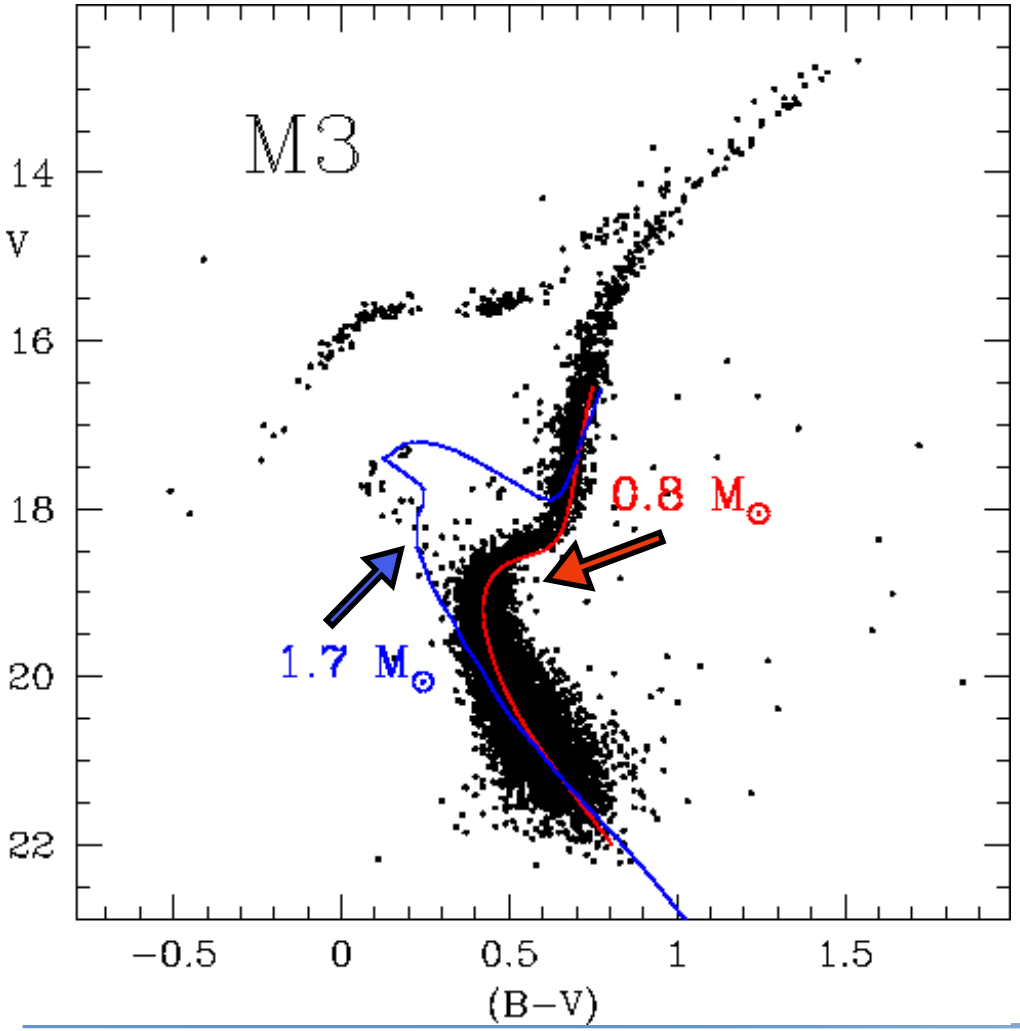
Blue Straggler Stars (BSS)



Flock of old "normal" tired stars getting progressively older and redder

Bunch of vigorous "apparently" young blue stars

STARS: younger ⟷ more massive



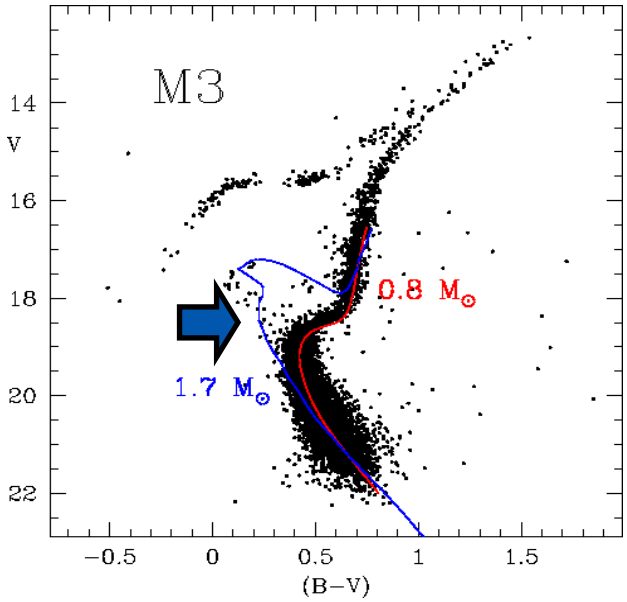
BSS
more massive
than normal stars

(also from direct measurements by Shara et al. 1997)

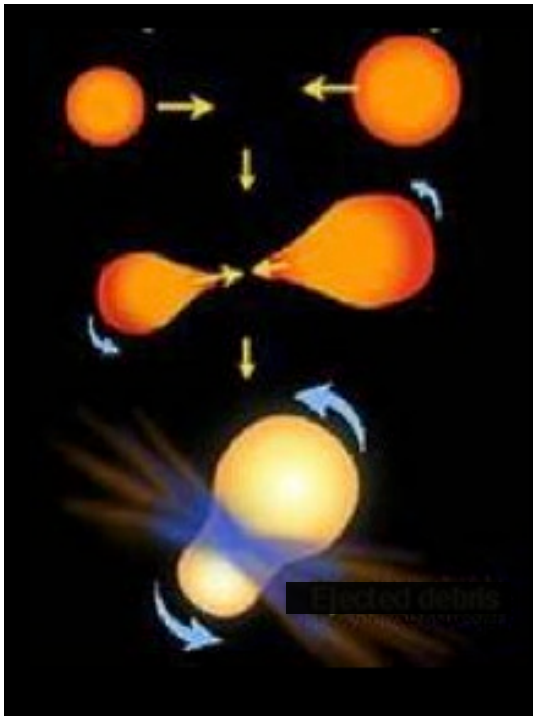
merger of
2 low-mass unevolved stars

Blue Straggler Stars (BSS)

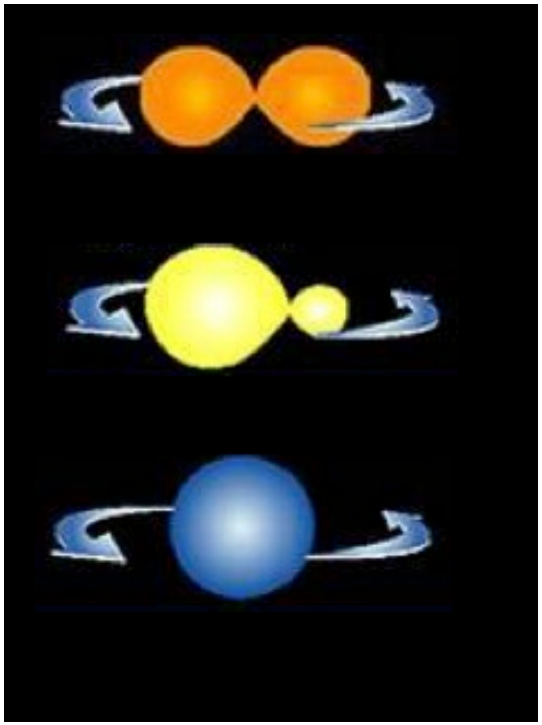
more massive than normal stars



collisional BSS



mass-transfer BSS



BSS → **crucial link between**

stellar evolution & stellar dynamics

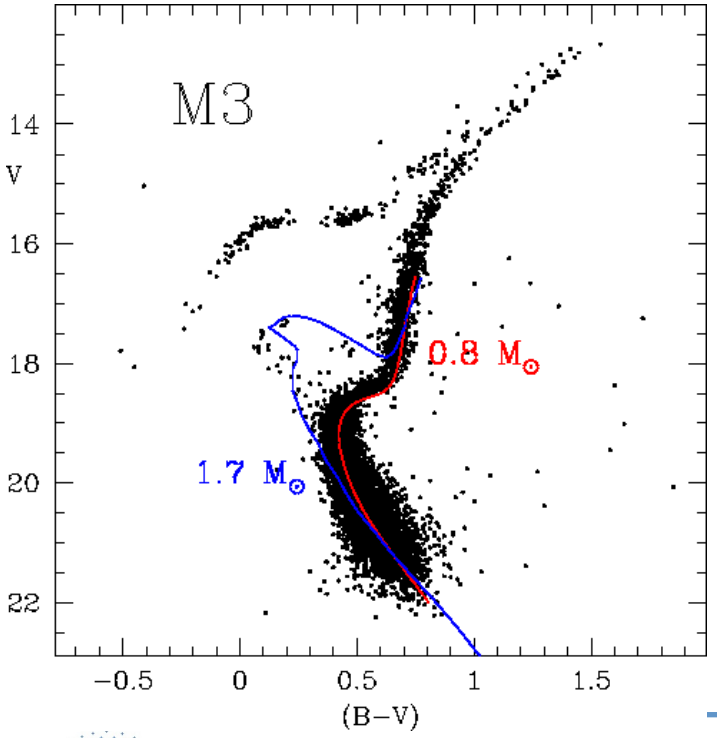
info about:

- **the dynamical history of the cluster**
- **the role of dynamics on stellar evolution**
- **the amount of binary systems**
- **the role of binaries in the cluster evolution**

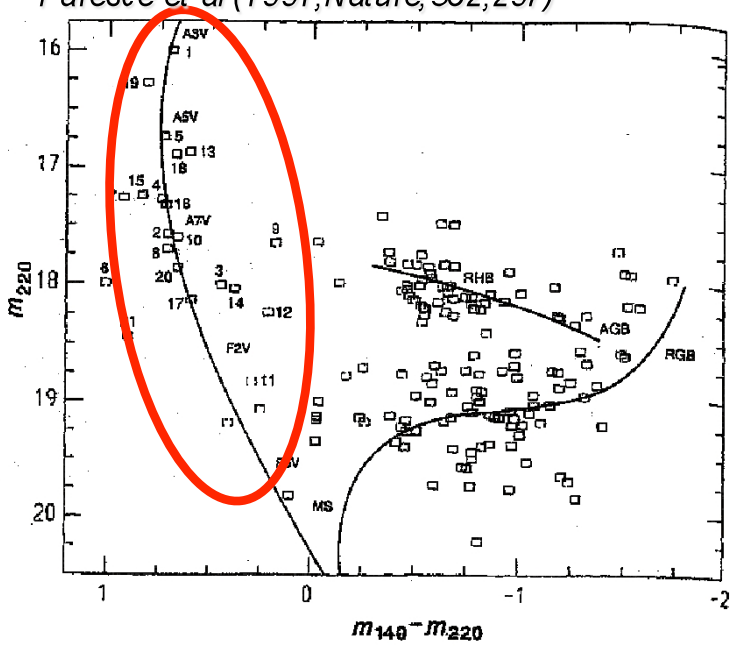
Blue Straggler Stars

loose GGCs low c, low ⇒ natural habitat for *BSS*

<1990 >1990



Paresce et al (1991, Nature, 352, 297)



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

some results: optical band

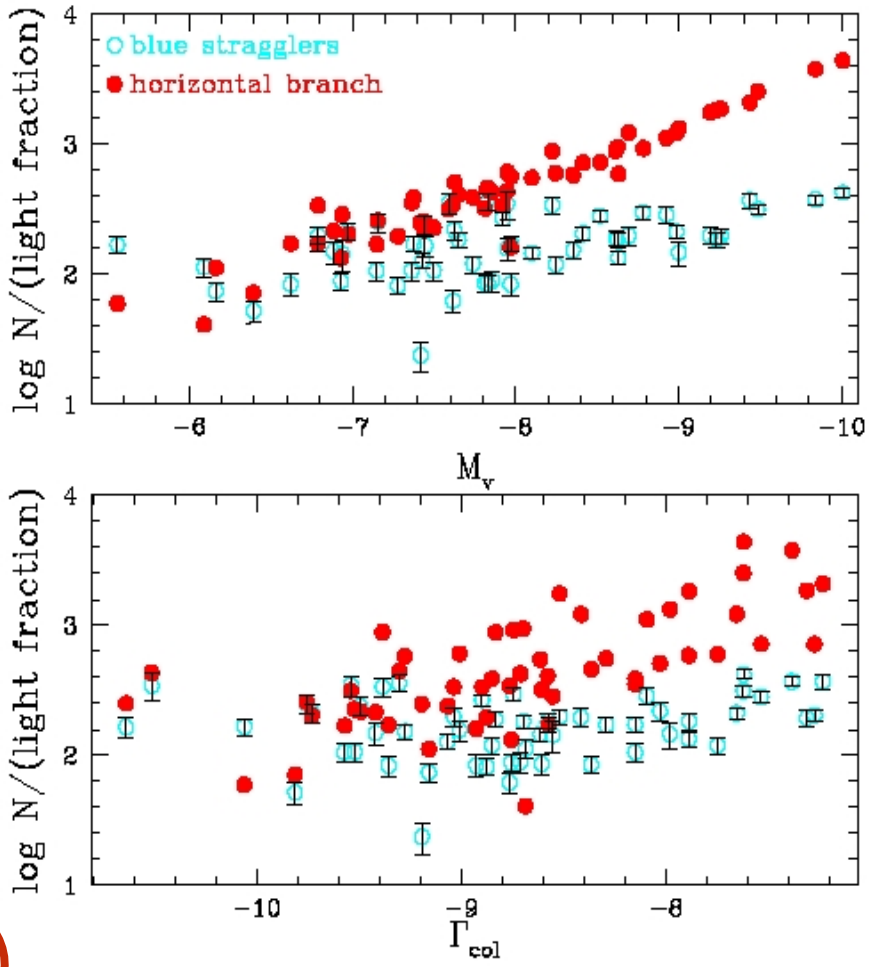
A catalog with 3000 BSS in 56 GGCs from HST optical obs

N(BSS)

- **varies by only a factor 10**
- **mildly dependent on cluster M**
- **independent of collision rate**

(Piotto et al. 2004; Davies et al. 2004)

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

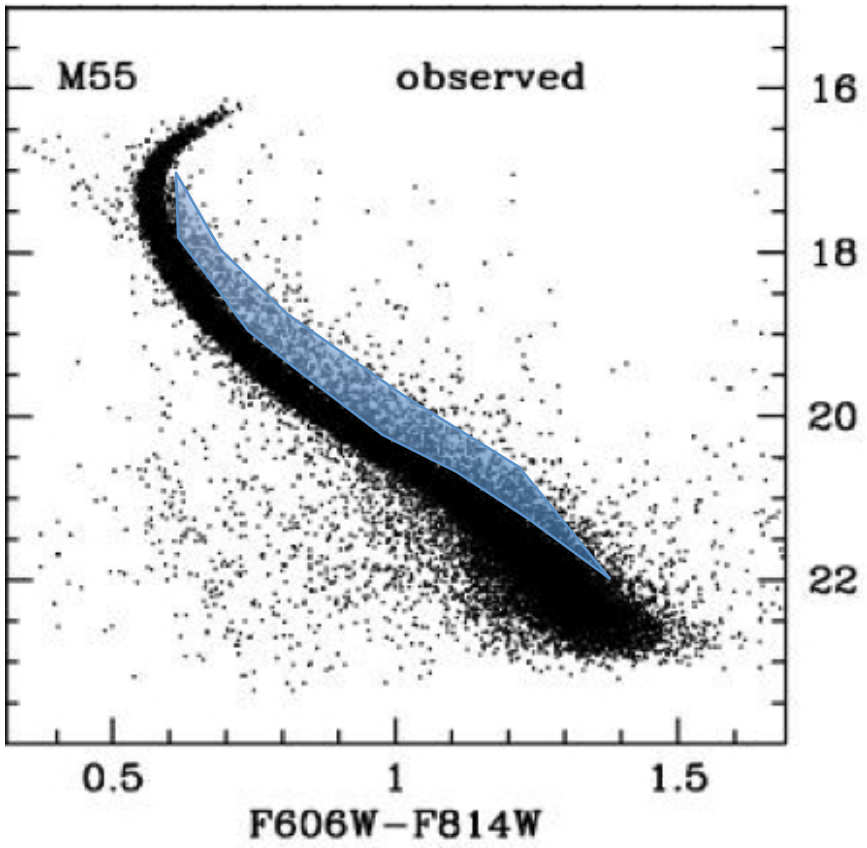


In agreement with previous suggestions by Fusi Pecci et al (1993), Baylin (1995), etc…

The BSS – binary link

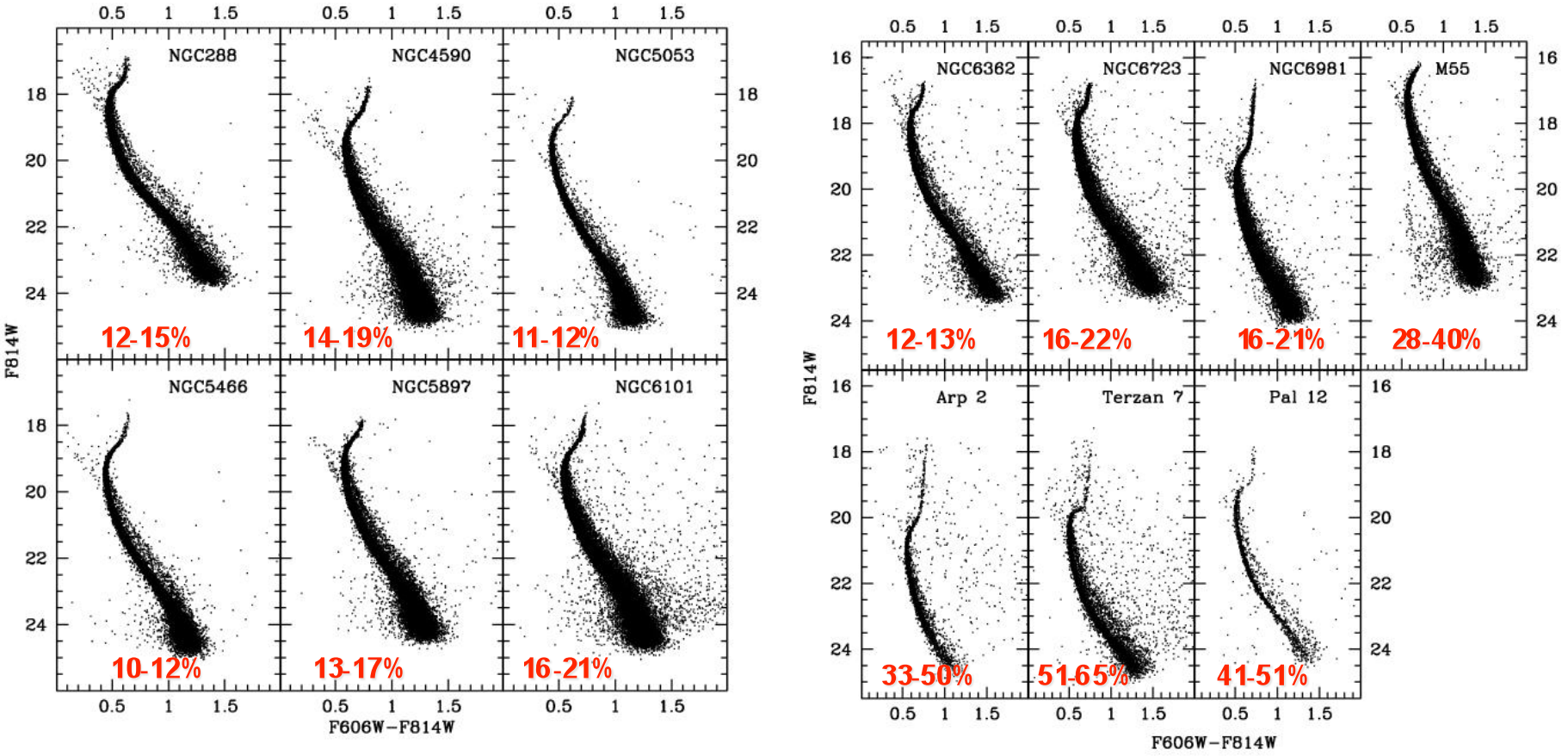
WHICH IS THE BINARY FRACTION IN GGC?

need very deep high-accuracy photometry (especially for high-density clusters)



Which is the binary fraction in GGCs ?

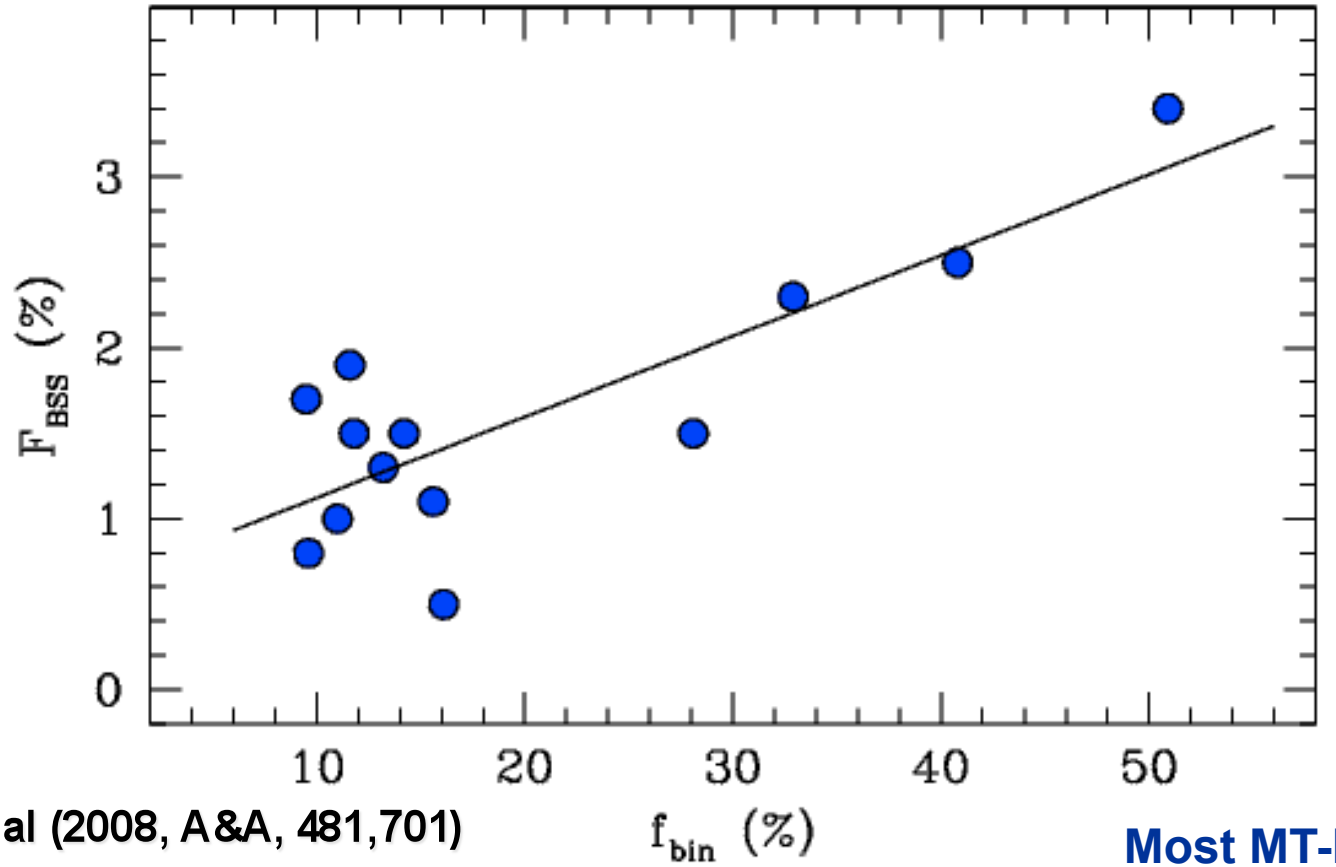
The Binary fraction in 13 low-density clusters from ACS-HST observations



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

BSS & binary fraction

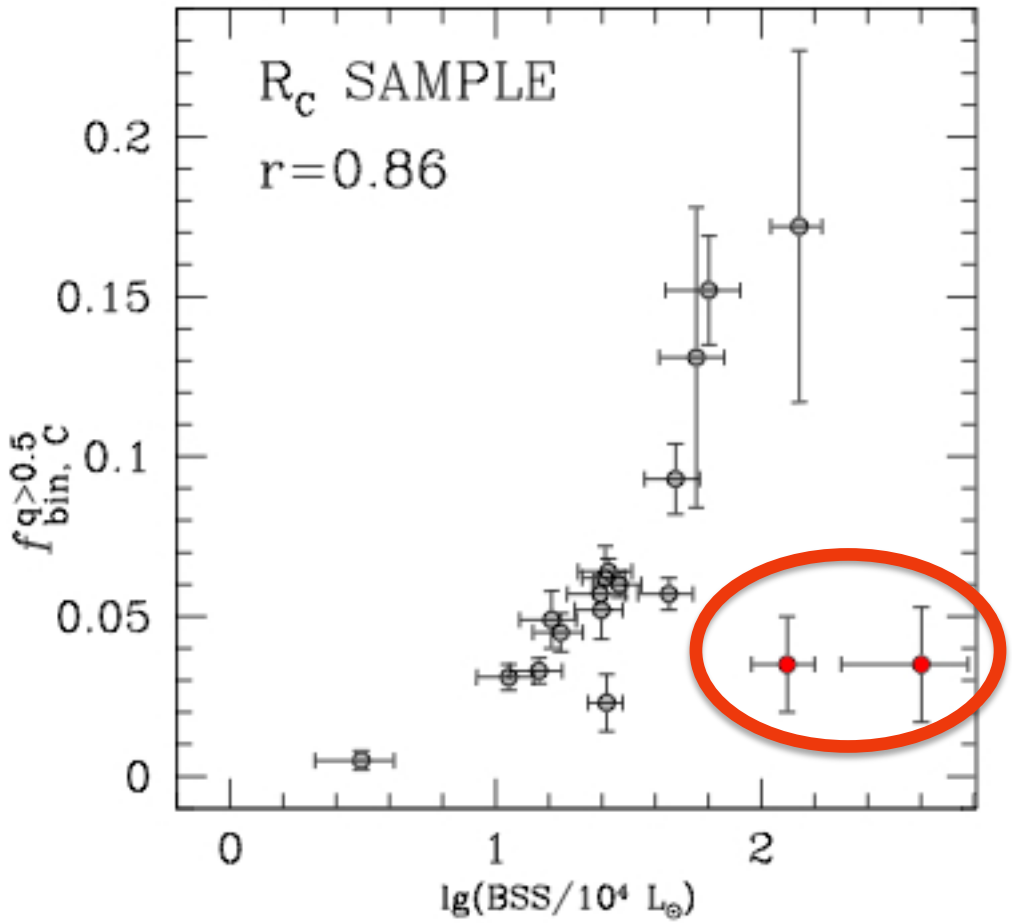
A strong correlation between BSS and the binary fraction has been found in 13 low-density (Log ρ <2.5)clusters



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

Most MT-BSS !!!

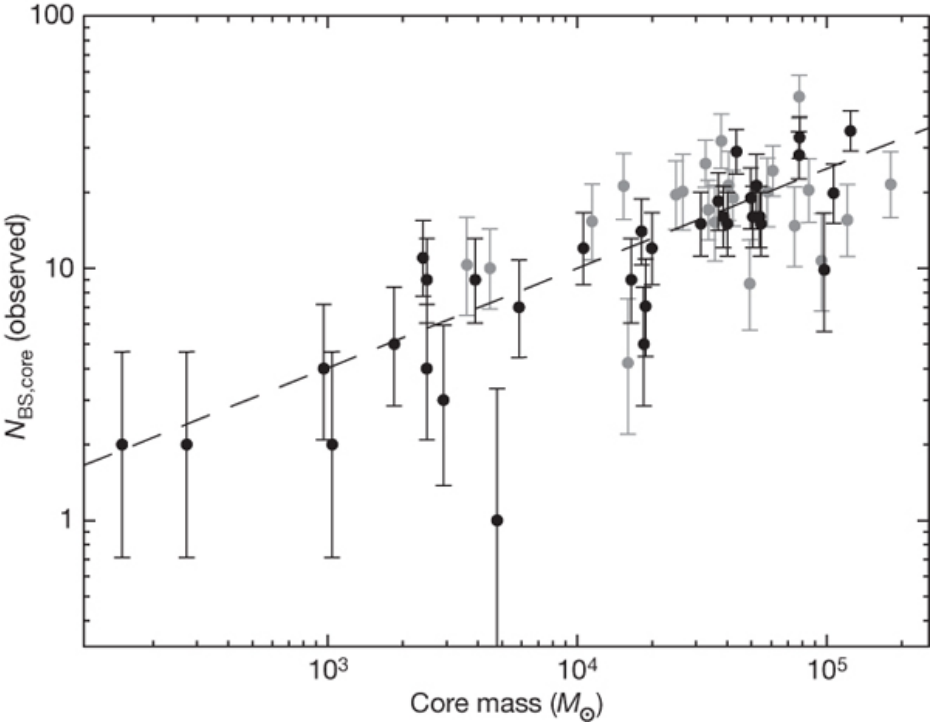
Milone et al (2012, A&A, 481,701) presented the binary fraction for a sample of 59 GGCs

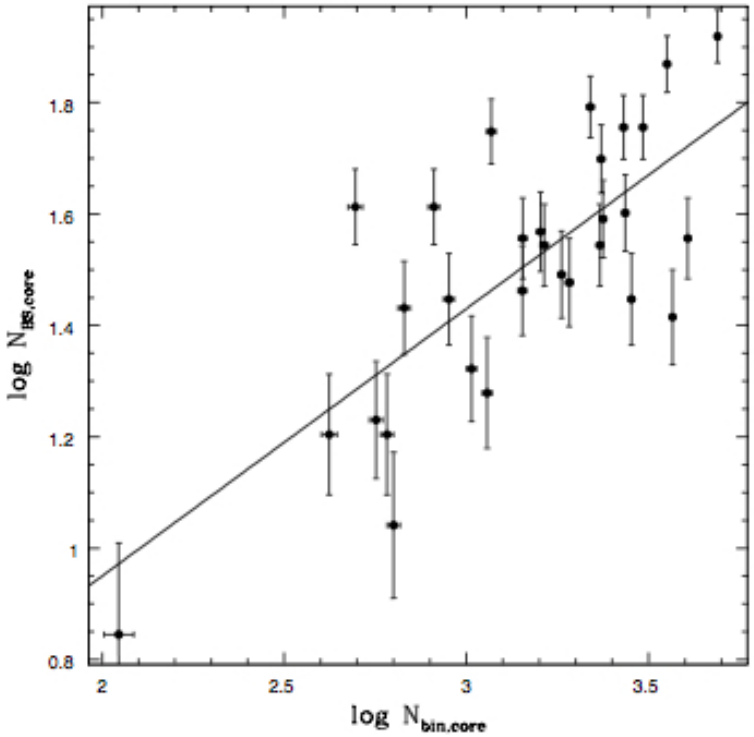


PCC

There is a correlation between the normalized BSS number and the binary fraction, but the plotted data seems to be only a sub-sample of the entire Milone sample of 59 GGCs

The observed number of core BSS vs the estimated core mass.





No correlation was found with the collisional parameter.This was interpreted as a strong evidence in favour of the binarity origin of BSS

Knigge et al (2009,Nature, 457,288)

However the correlation with the binary fraction is sensibly **weaker** than that with the core mass

Leight et al (2012,MNRAS, in press)

1. NO CORRELATION HAS BEEN FOUND BETWEEN N_{BSS} AND Γ

2. THE STRONGEST CORRELATION HAS BEEN FOUND WITH THE MASS OF THE CORE

3. THE NORMALIZED NUMBER OF BSS SEEMS TO SCALE WITH THE FRACTION OF BINARIES
(at least in the low-density environment)

BUT

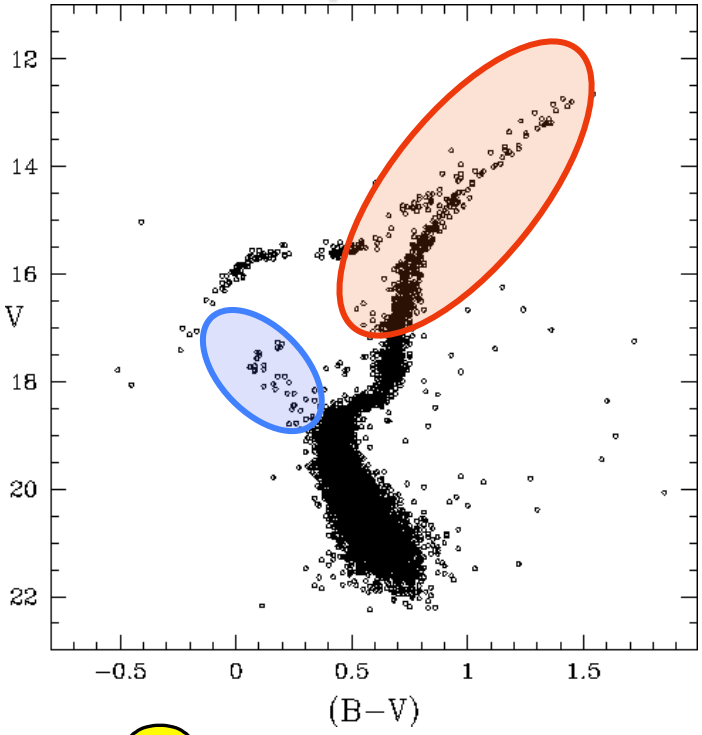
1. BSS OBSERVED IN THE CORE DID NOT FORM ALL IN THE CORE
(probably a significant part of them formed outside the core and then migrate there)

2. THE BINARY FRACTION IN THE CORE COULD BE QUITE UNCERTAIN ESPECIALLY IN THE DENSEST CLUSTERS

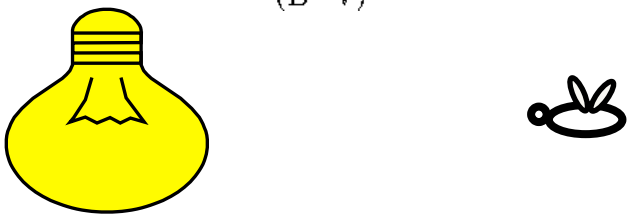
3. THE BSS SAMPLE COULD BE INCOMPLETE IN THE DENSEST CLUSTERS

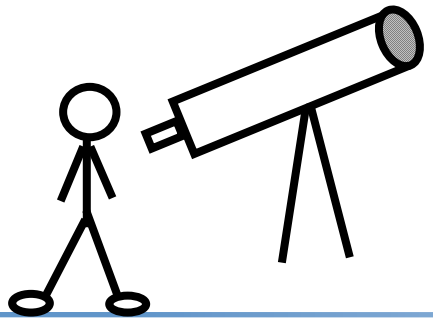
BSS observations are intrinsically difficult in the optical bands even with HST

RGB/AGB much brighter than BSS



… like trying to distinguish
a fire-fly in the dark Chilean night
while having a HUGE light bulb
just in front of us!



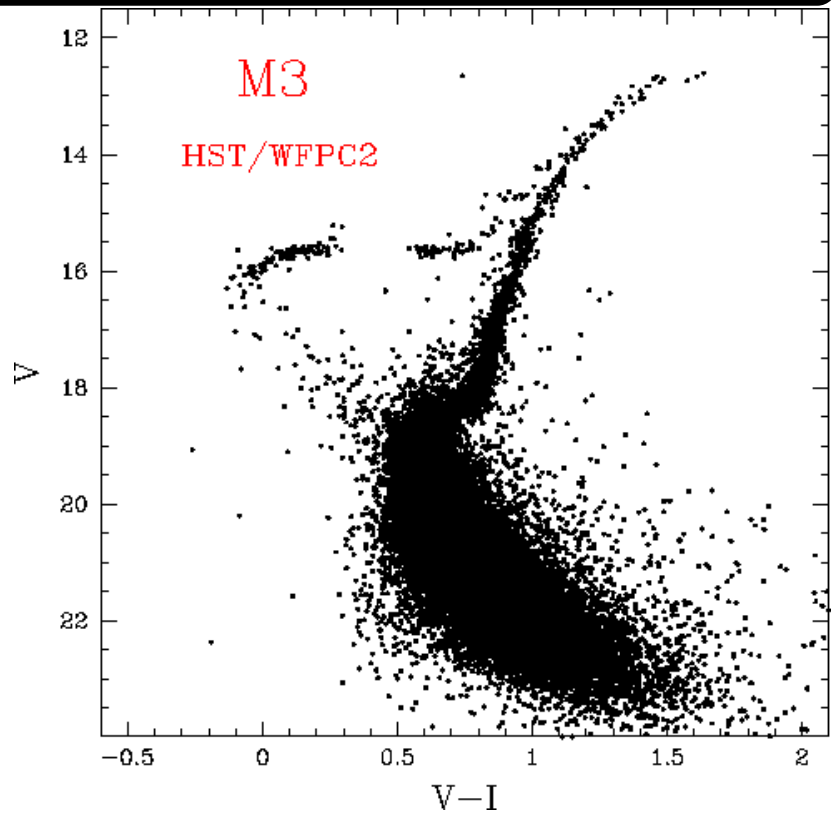


UV

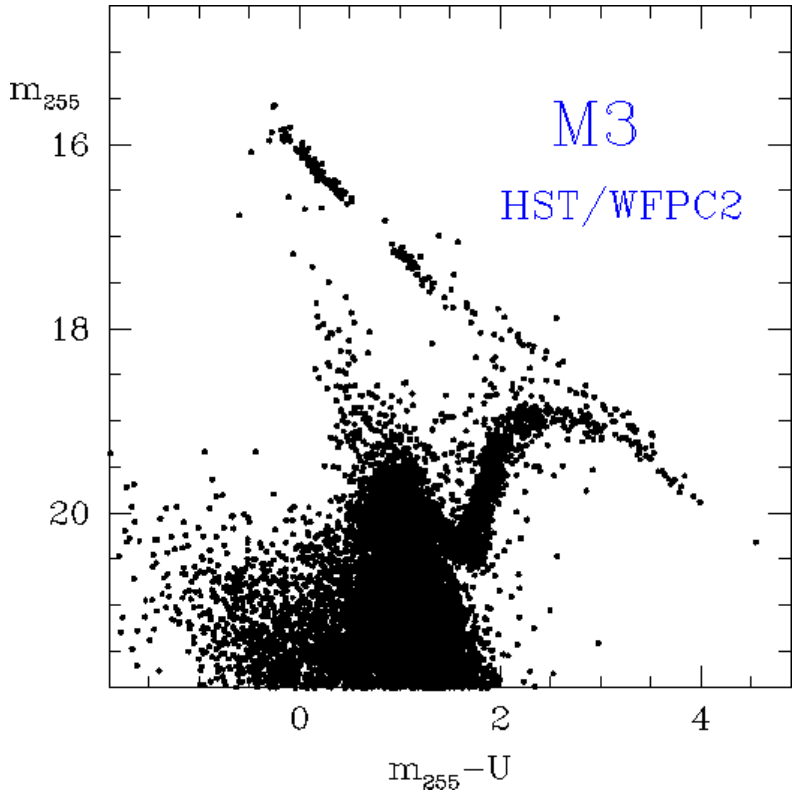
UV sensitivity , high resolution

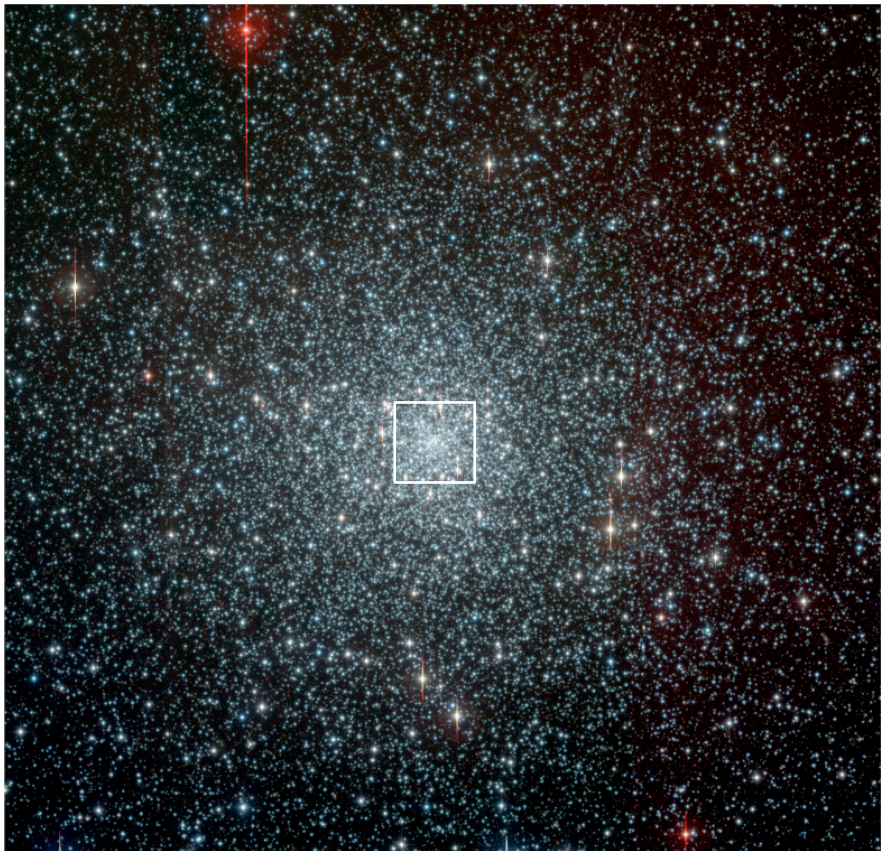
systematic studies of hot SPs
even in the core of high density GGCs

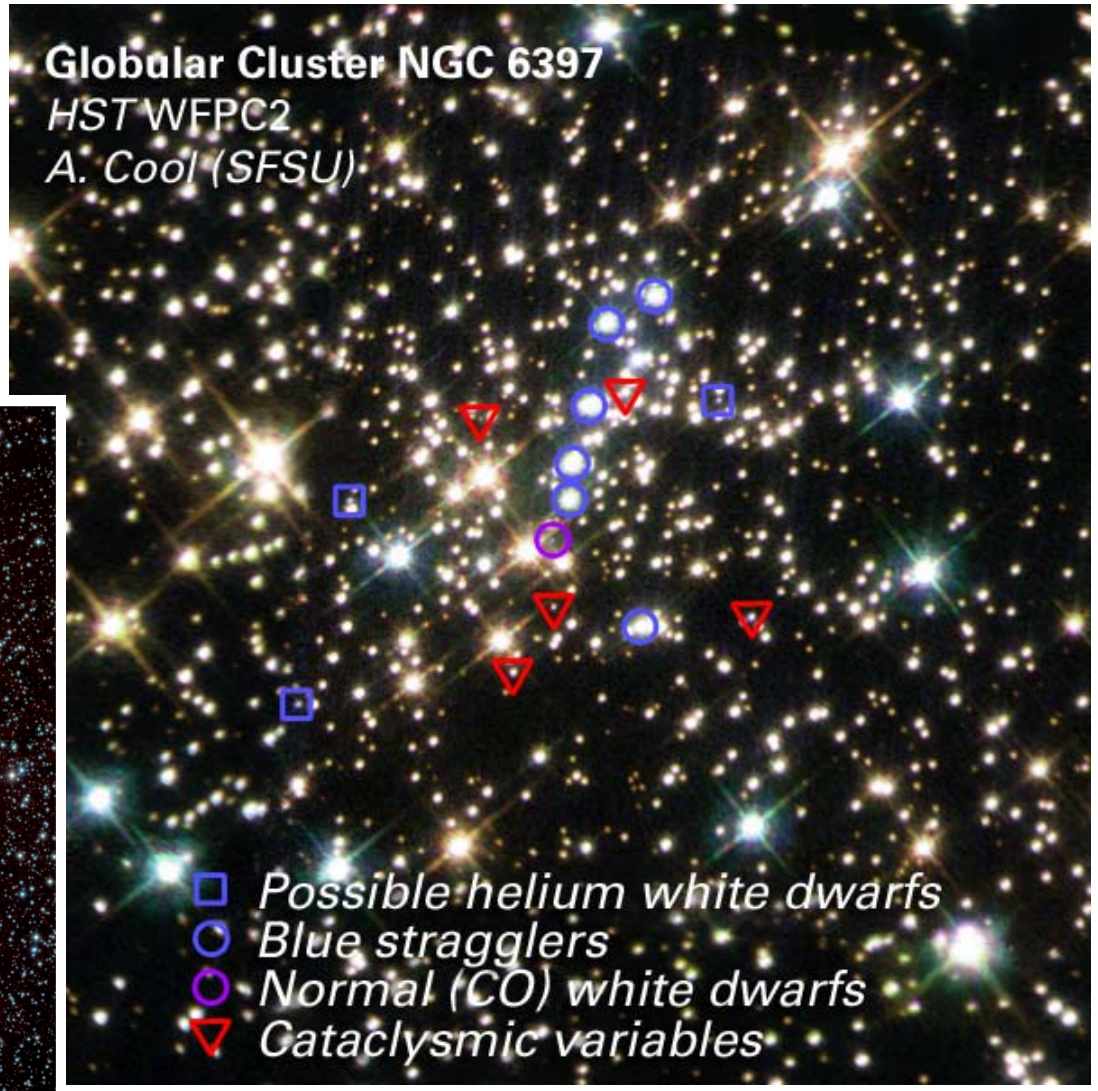
The "classical" plane



The UV plane

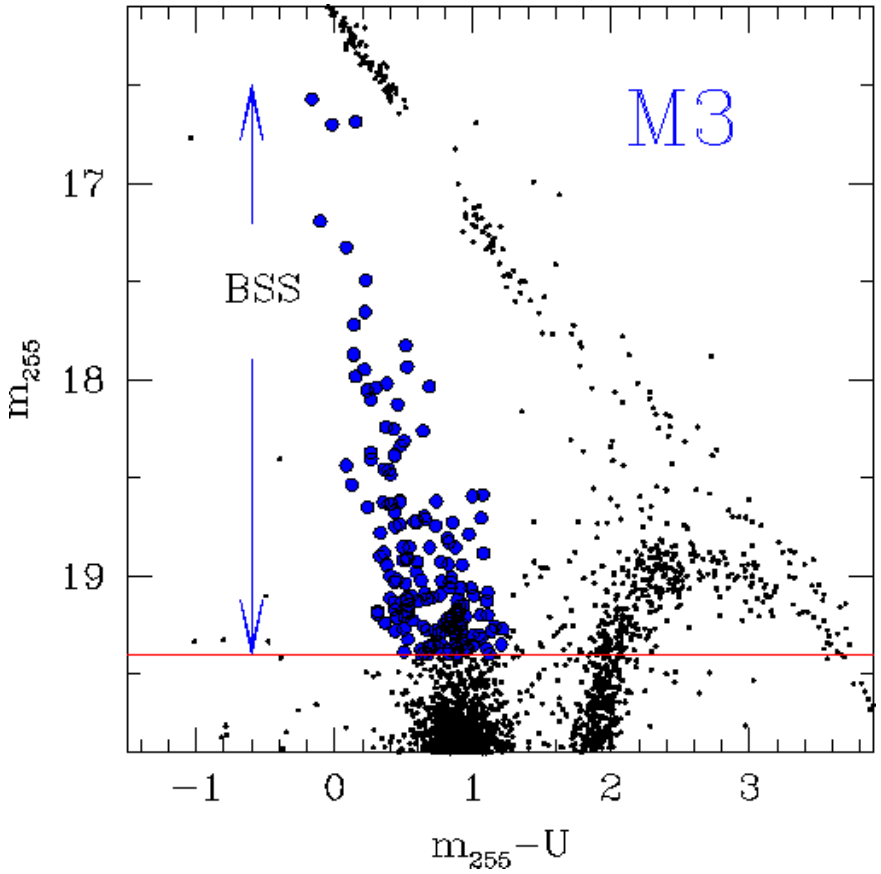






Globular clusters images in UV are not dominated by the red giant light, and therefore are significantly less crowded.

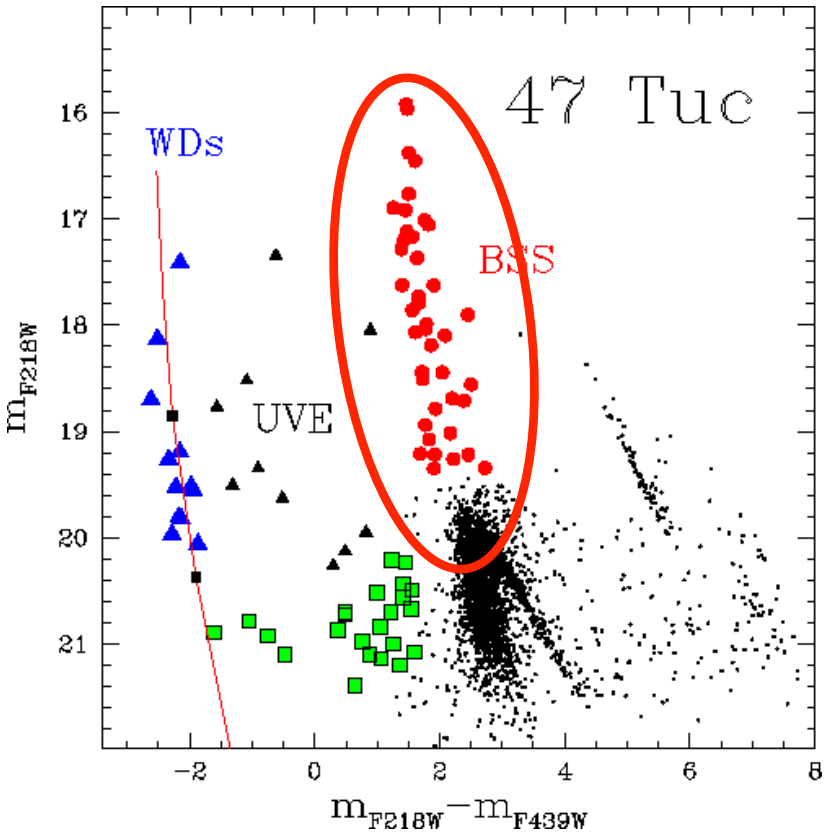
BSS in the UV:



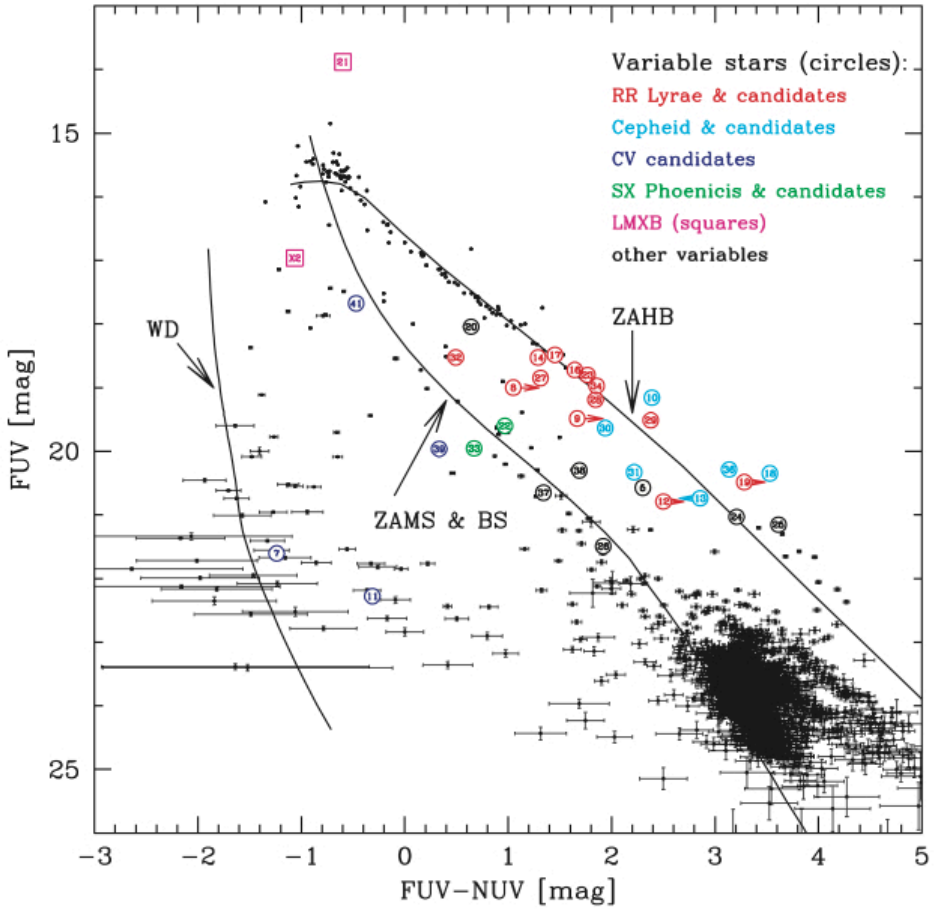
Ferraro et al (1997,A&A,324,915)

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

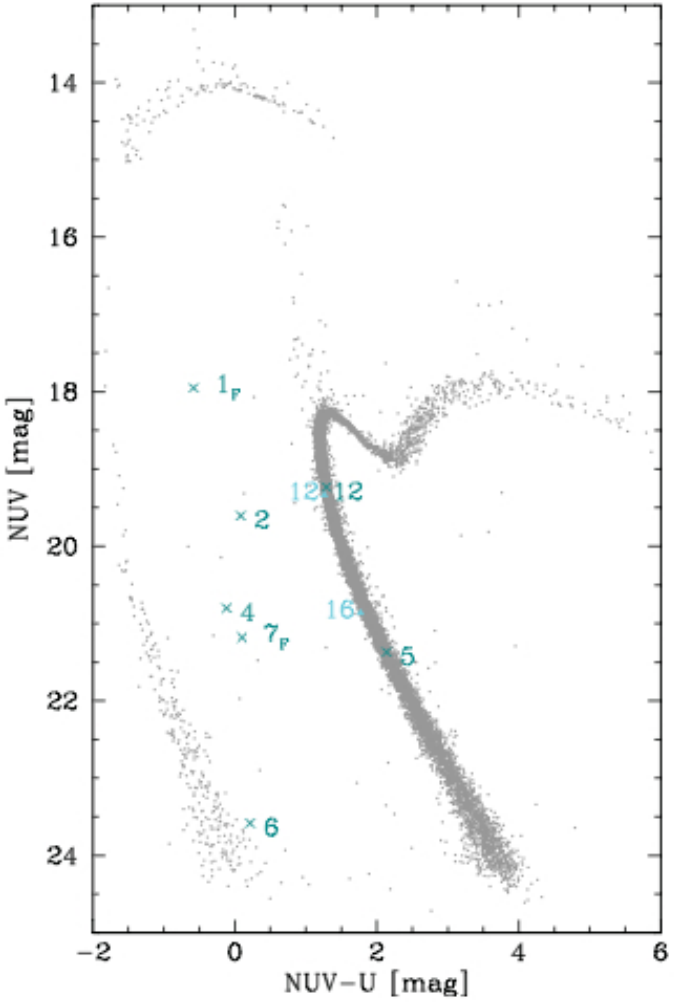
- the distribution is almost vertical
- span more than 3 magnitudes



BSS in the UV:

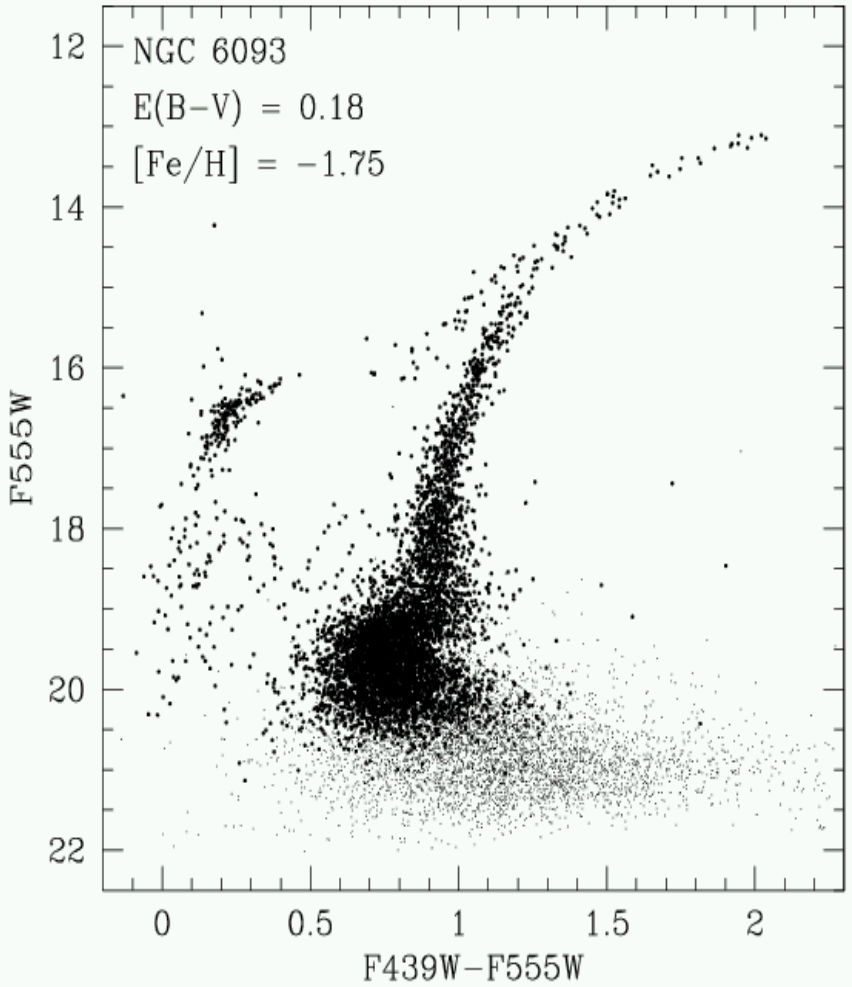


Dieball et al (2007,ApJ,670,379)

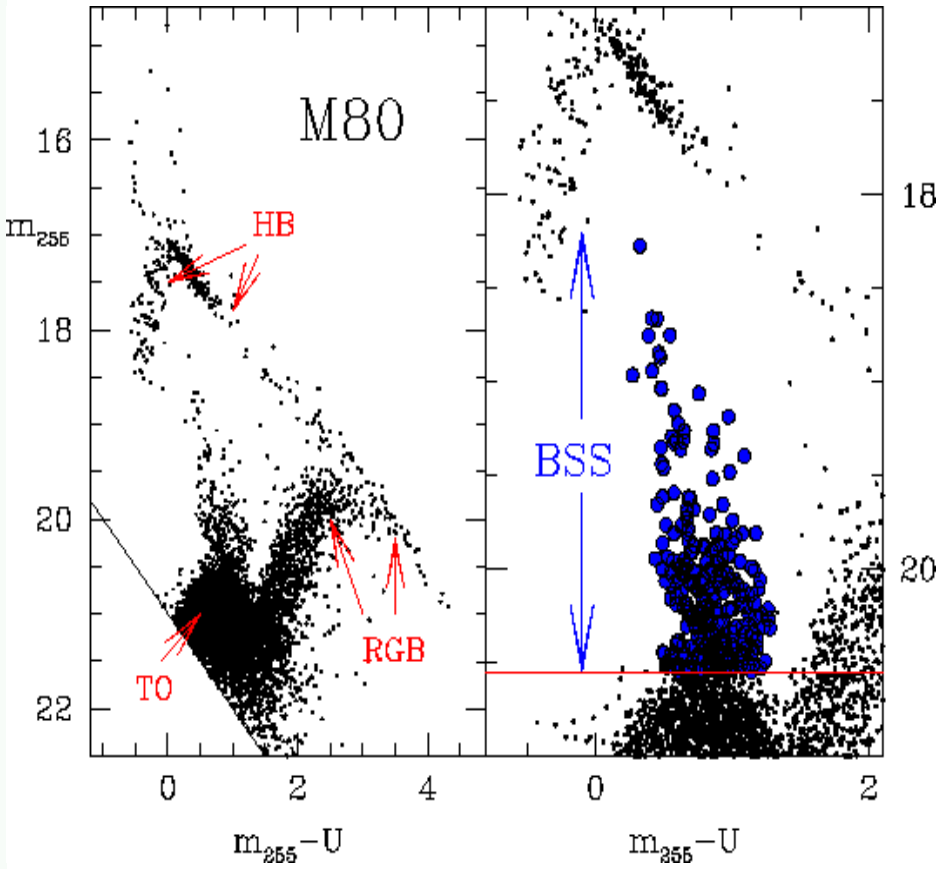


Thompson et al (2012, MNRAS,423,2901)

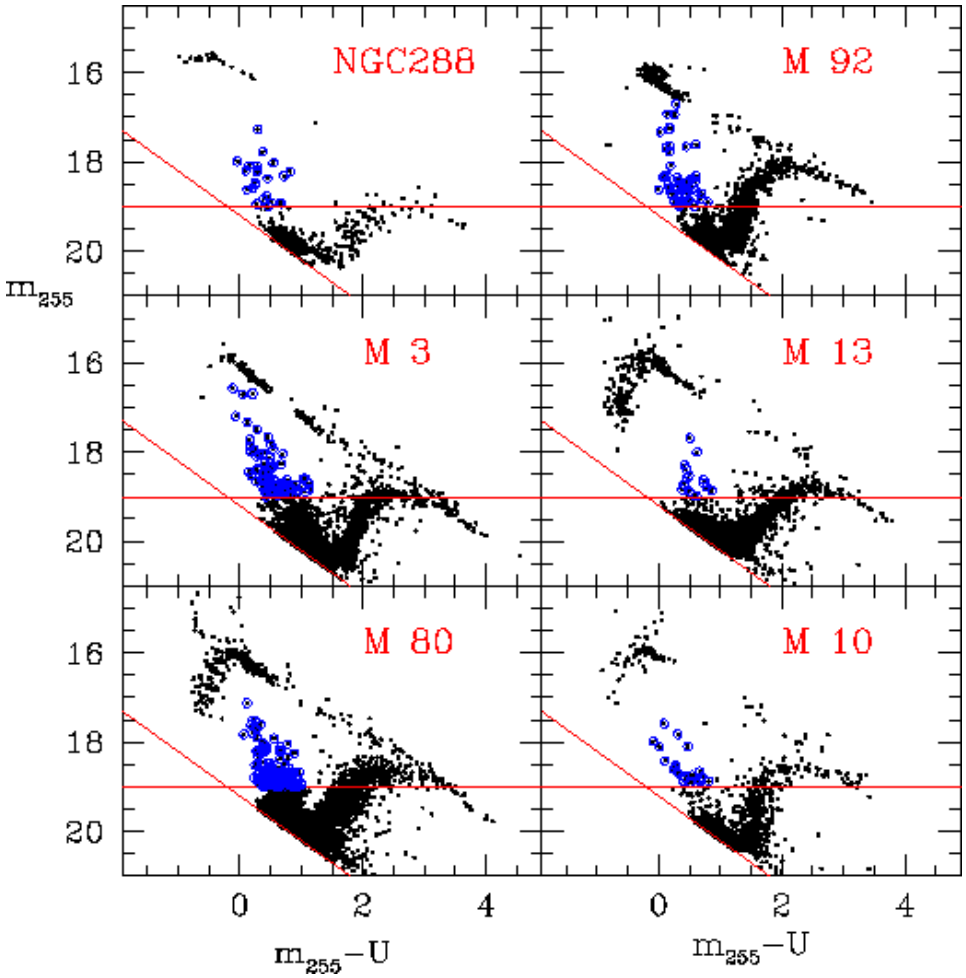
OPTICAL


NGC 6093
E(B−V) = 0.18
[Fe/H] = −1.75
F555W
F439W−F555W
12
14
16
18
20
22
0
0.5
1
1.5
2

UV


M80
HB
RGB
TO
BSS
m_{255}
$m_{255}-U$
16
18
20
22
0
2
4

Direct comparison of BSS populations



N_{BSS} must be normalized to the cluster population

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

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

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

Direct comparison of BSS populations

twin clusters

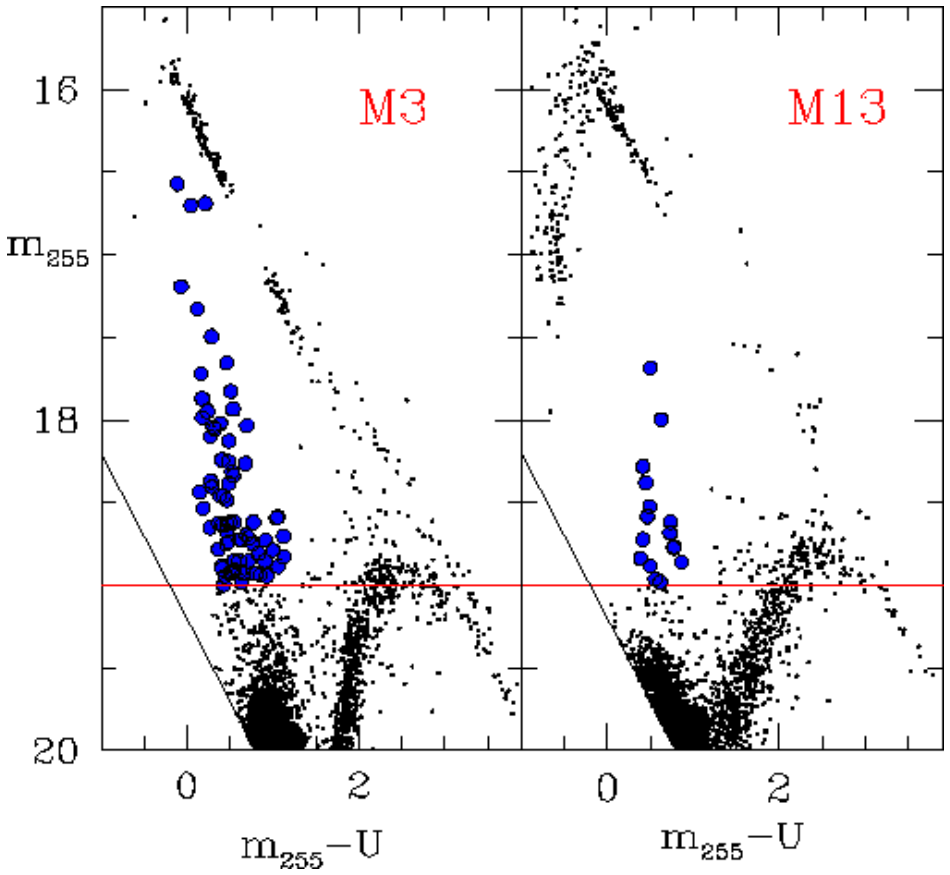
M 3

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

The BSS fraction apparently scales as the binary fraction by Milone et al (2012): F_{bin} =0.027 (for M3) and F_{bin} =0.005 (for M13)

Direct comparison of BSS populations

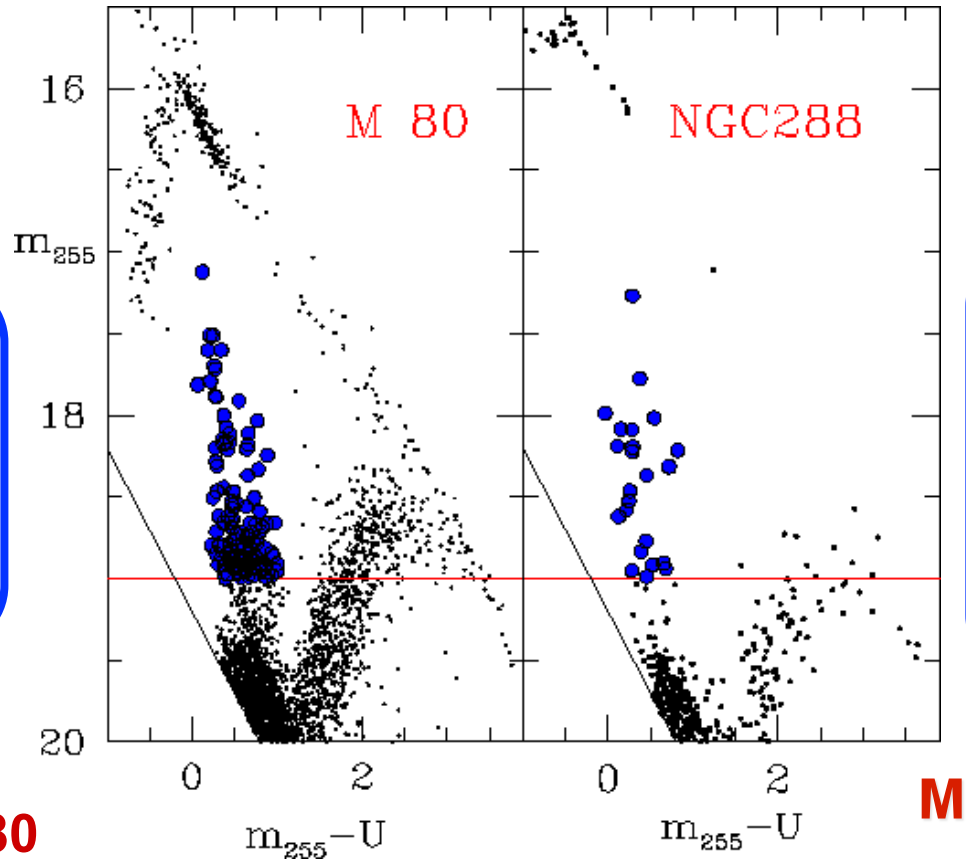
Different ρ_0

M 80

Log ρ_0 = 5.8 M_s/pc^3

NGC 288

Log ρ_0 = 2.1 M_s/pc^3



N_{BSS} = *129*

$\mathcal{F}$ = 1.0

if only the PC is considered

N_{BSS} = *24*

$\mathcal{F}$ = 0.92

The largest specific frequency ever observed!
In one of the lowest density clusters…!

COLL-BSS in M80

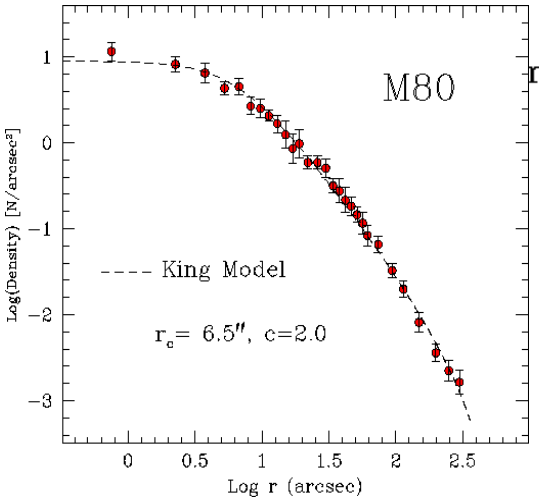
MT-BSS in NGC 288 (F_{bin} =0.06)

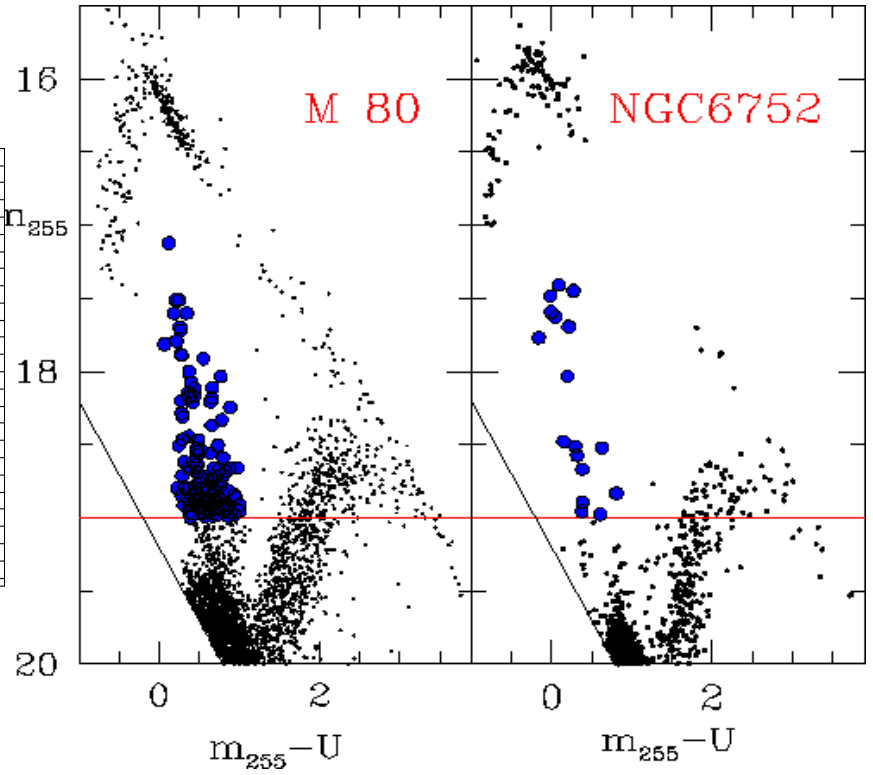
comparable efficiency in their respective environment ?

Direct comparison of BSS populations

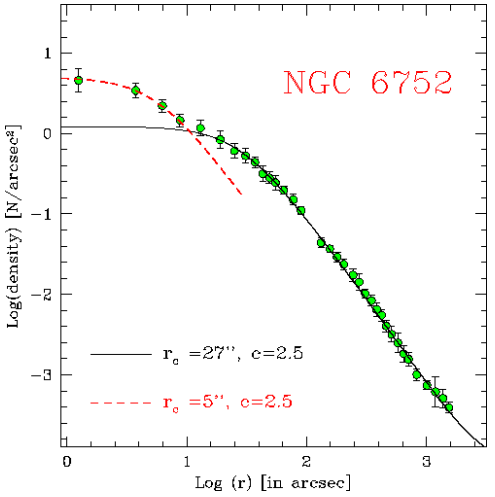
different dynamical status

M 80
collapsing





NGC 6752
PCC



N_{BSS} = *129*

$\mathcal{F}$ = 0.44

N_{BSS} = *17*

$\mathcal{F}$ = 0.16

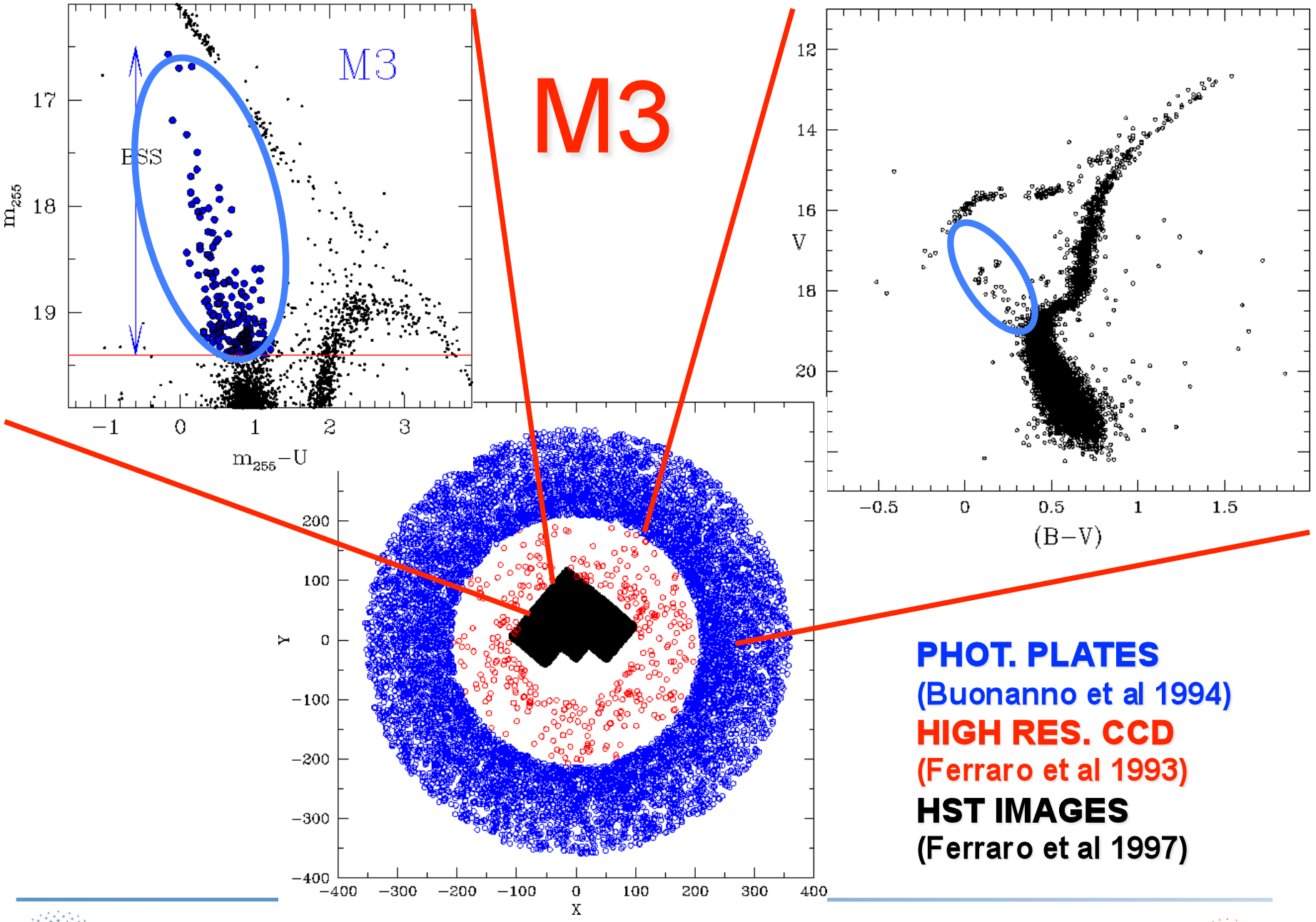
are binaries preventing the core collapse ?

are hard binaries destroyed during the collapse ? (F_{bin}=0.017)

The BSS radial distribution

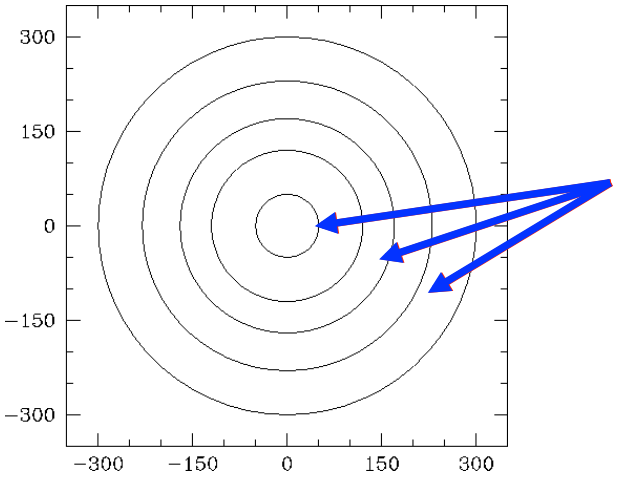
… However, the population of BSS in the central region of clusters is only part of the story:
in fact the global BSS radial distribution contains important signatures of the cluster dynamical evolution

.. The second part of the story starts back in 1993 with M3, the cluster where the BSS were identified the first time…


M3
M3
BSS
m_{255}
$m_{255}-U$
V
(B−V)
Y
X
PHOT. PLATES
(Buonanno et al 1994)
HIGH RES. CCD
(Ferraro et al 1993)
HST IMAGES
(Ferraro et al 1997)

BSS in M3

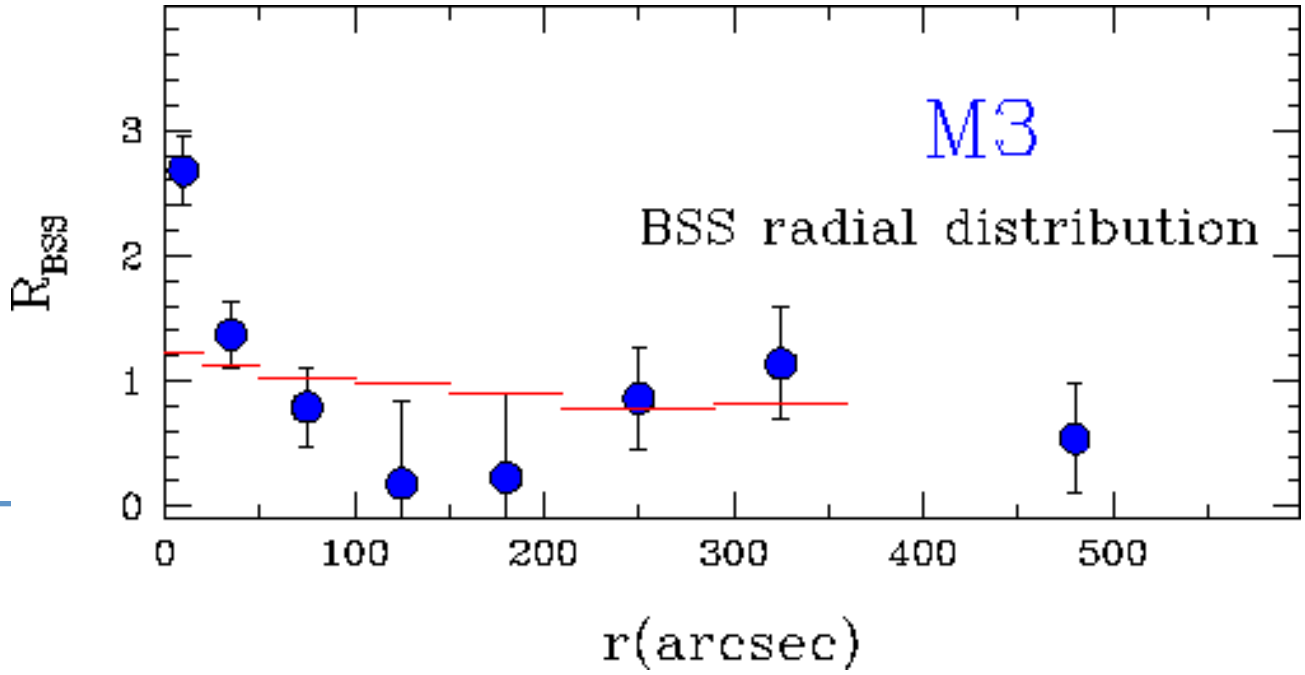
The first complete coverage of the entire cluster extension



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

The BSS radial distribution is BIMODAL

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

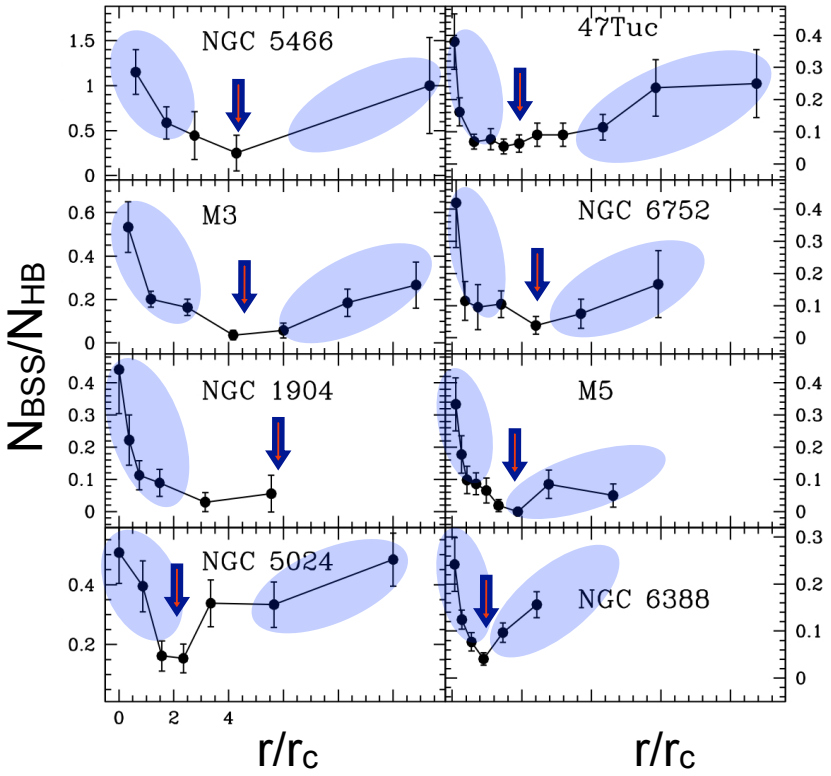


Is this distribution really "peculiar" & unique ?

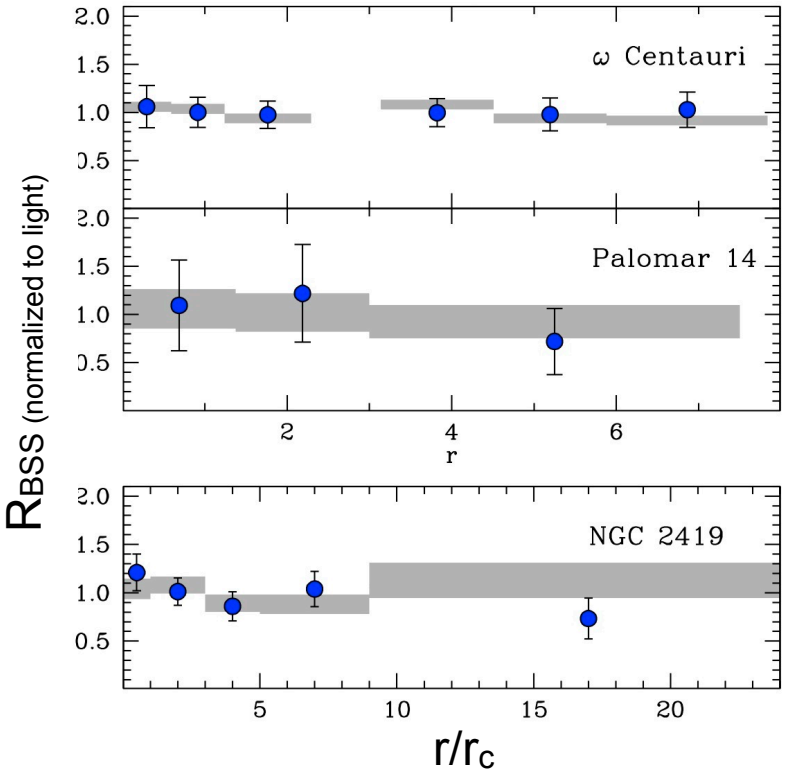
Cosmic-Lab

The BSS radial distribution

peaked/bimodal



flat

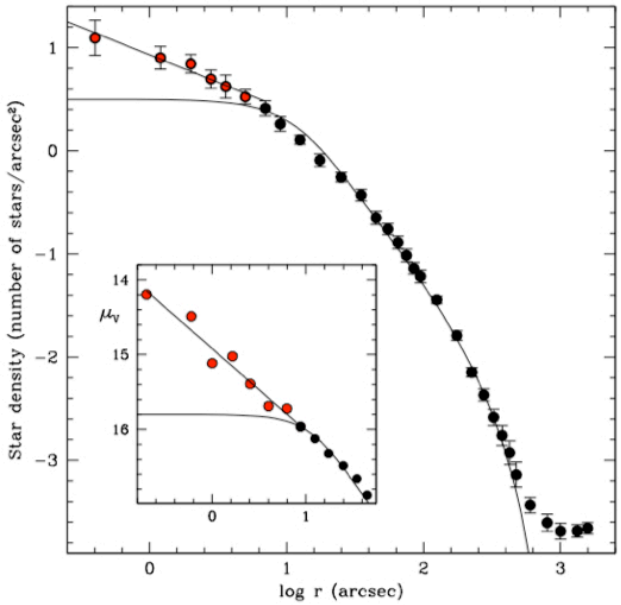


probes the degree of mass-segregation and the efficiency of dynamical friction

(Barbara will talk about this in a few minutes)

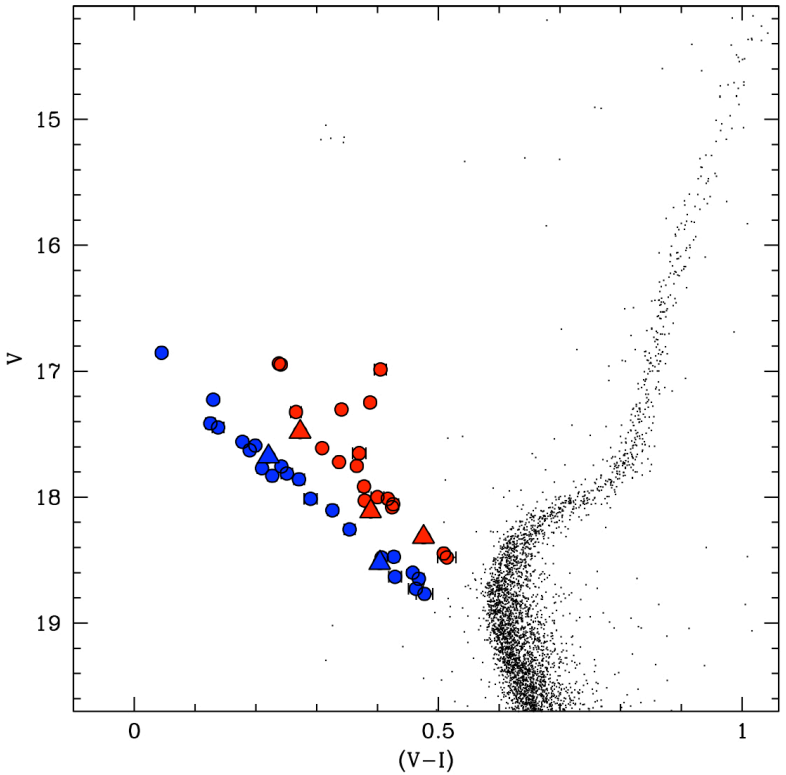
…. Indeed we can do even more….

M30 (NGC 7099)



2 distinct sequences of BSS !!

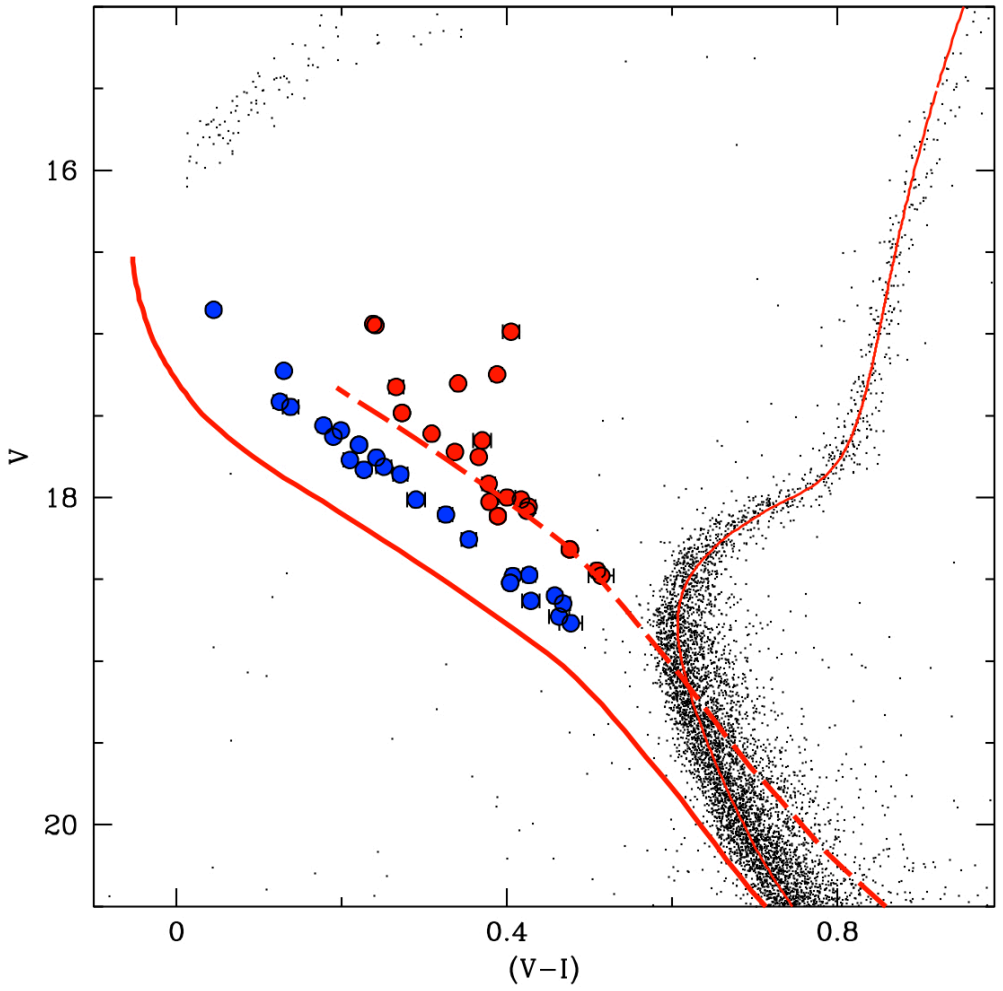
Ferraro et al. (2009, Nature 462, 1028)



M30 (NGC 7099)

- blue-BSS sequence well reproduced by collisional isochrones of 1-2 Gyr

red-BSS sequence is consistent with the locus of mass transfer binaries



The blue-BSS population must have formed 1-2 Gyr ago in a short lived event

Possible link to the PCC event

This discovery opens the possibility of using BSS to date the core collapse event

(Emanuele will talk about this in a few minutes)

BSS chemical properties

Searching for chemical/kinematical signatures of the formation mechanism on the surface of BSS

How to distinguish COL-BSS from MT-BSS?

ROTATION: controversial predictions about COL-BSS

COL-BSS are FAST rotators
(Benz & Hills 1987)

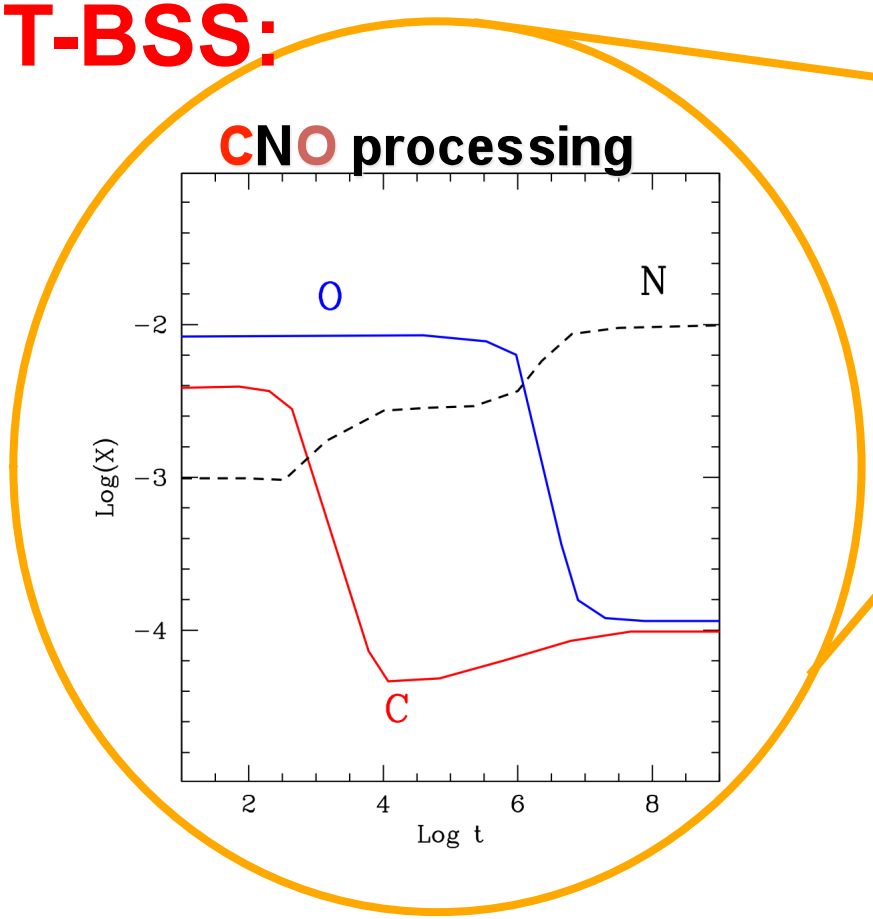
COL-BSS are NOT FAST rotators
(Leonard & Livio 1995)

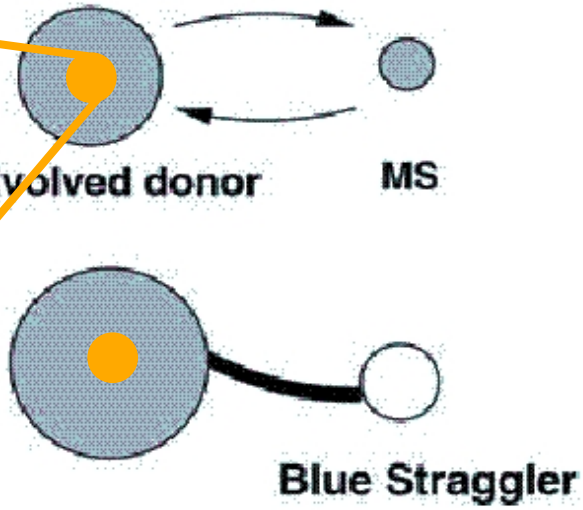
CHEMICAL ABUNDANCES:

COLL-BSS:
negligible mixing between inner cores and outer envelopes
(Lombardi et al. 1995)

MT-BSS:
incomplete CN-burning products expected on the surface of the star
(Sarna & de Greve 1996)

MT-BSS:





material on the BSS surface
comes from the core of the donor

C and O DEPLETION
expected on the BSS surface

Searching for chemical signatures of the BSS formation process

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

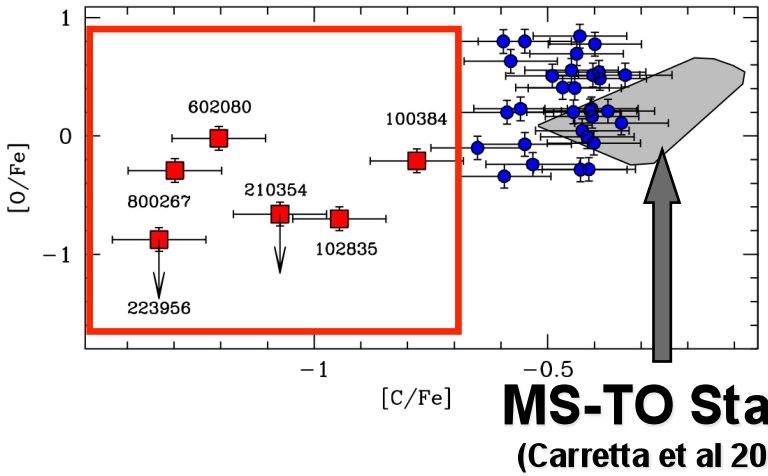
C abundance from CI line at λ=9111.8 A
O abundance from OI line at λ=7774 A

47 Tuc

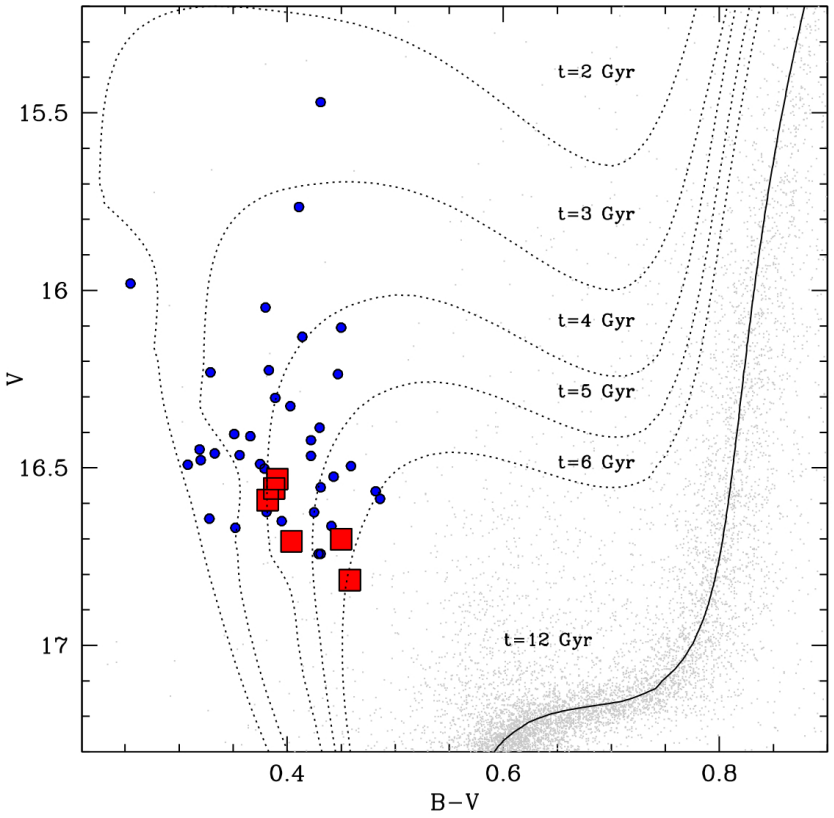
Ferraro et al 2006, ApJ,647,L56

A sub-population of CO-depleted BSS

43 BSS selected over the entire cluster extension

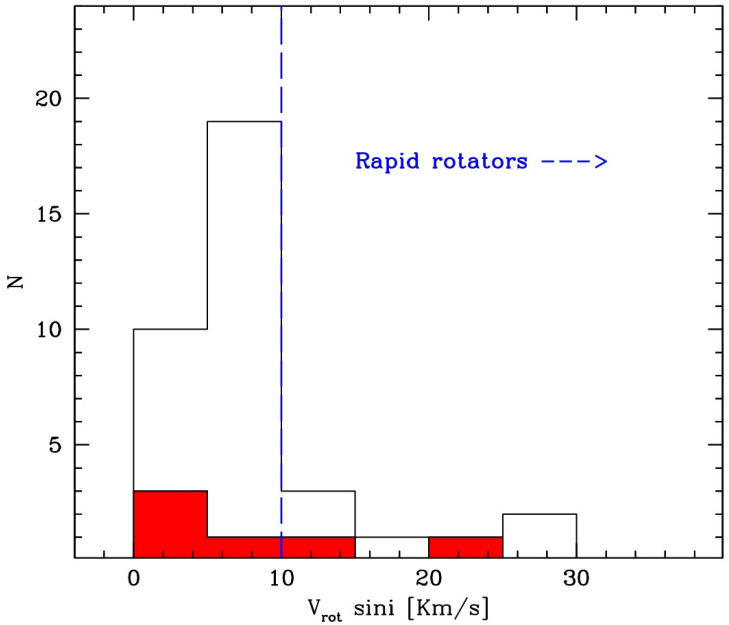


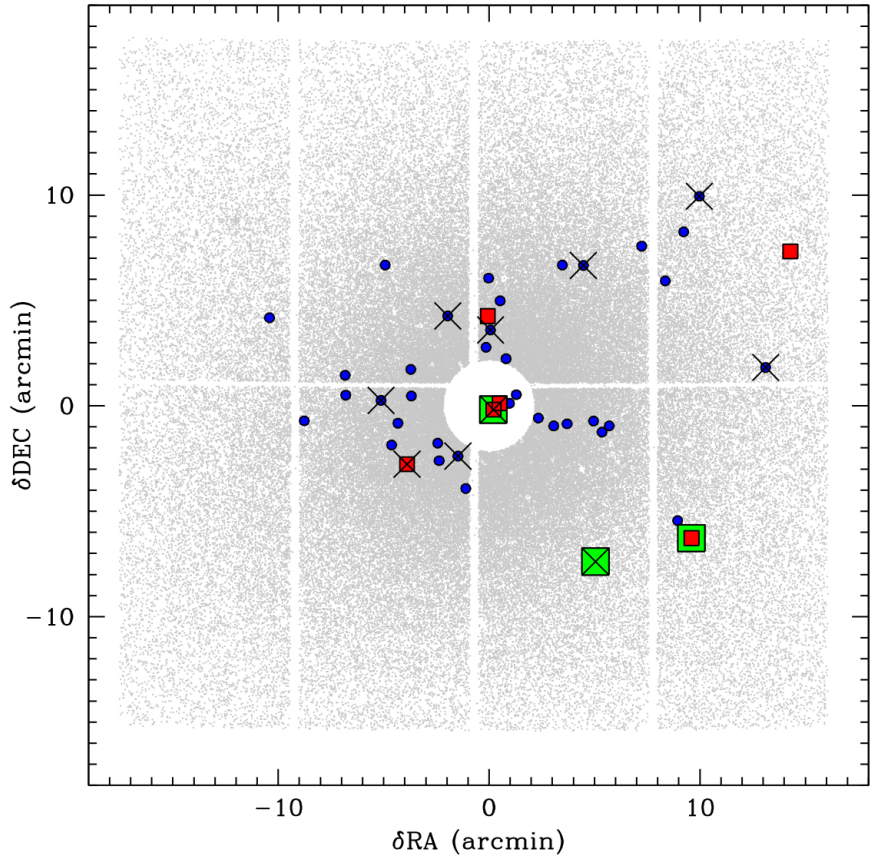
MS-TO Stars
(Carretta et al 2005)



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

Most BSS are slow rotators





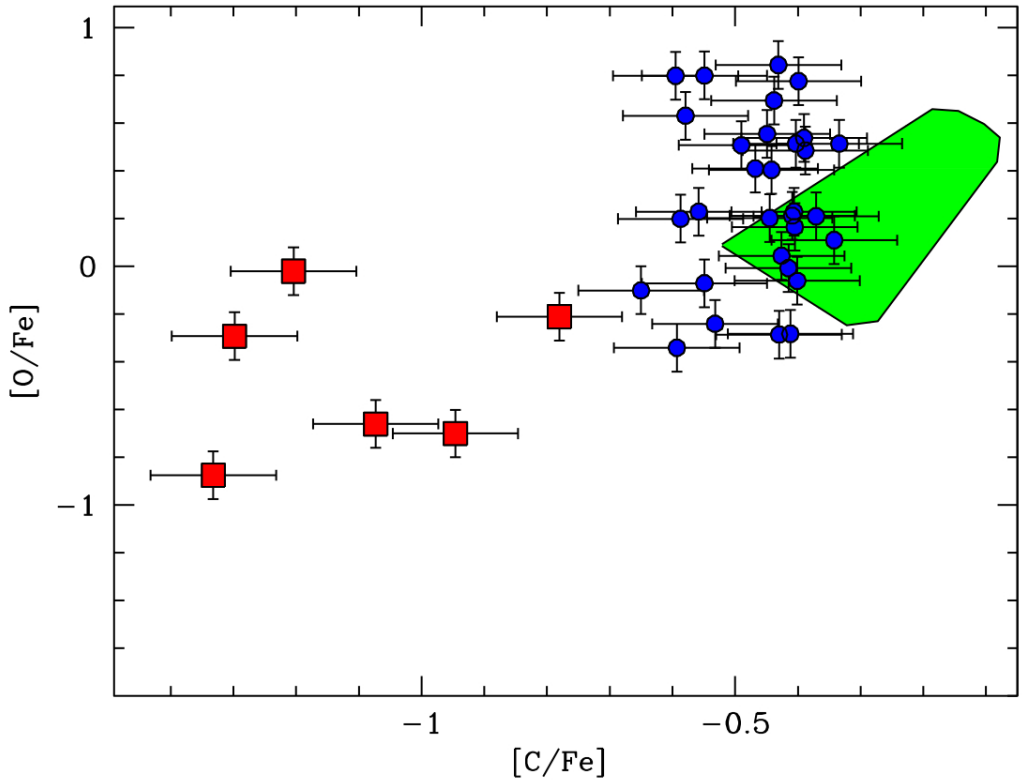
6 C,O depleted ( )

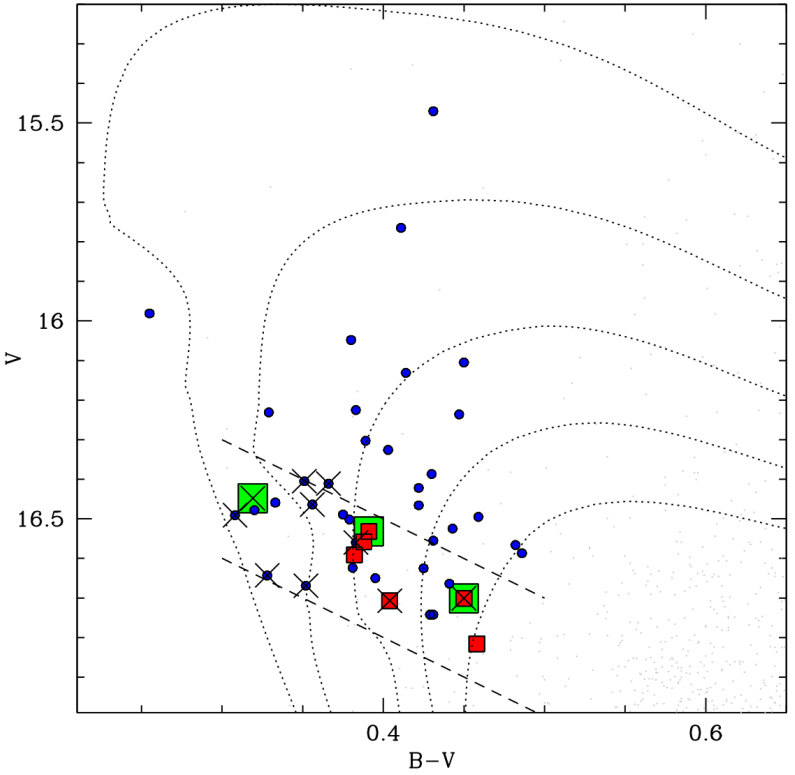
10 "moderate" rotators (X)

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

Stage 1- trasferred material is un-processed. BSS appear as normal stars

Stage 2- trasferred material comes from CNO processed region C first and then O appear depleted





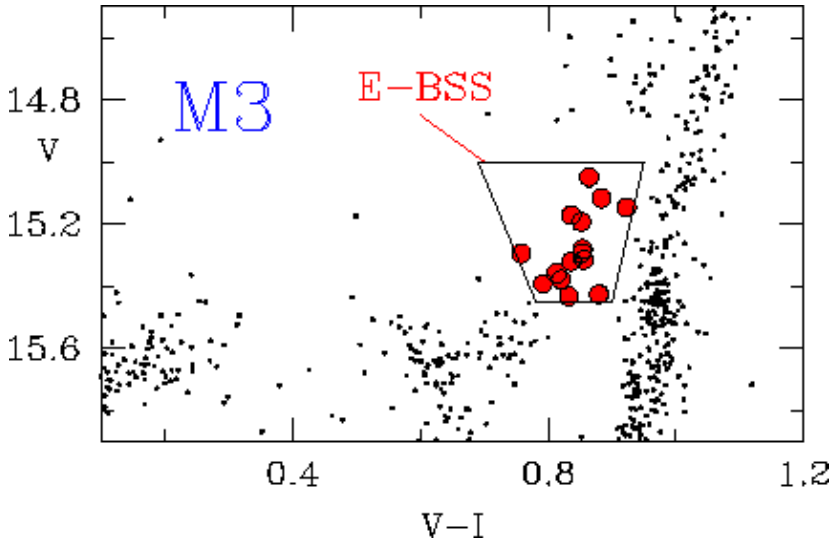
Stage 3- after the merge the BSS would appear as a non-variable CO depleted star

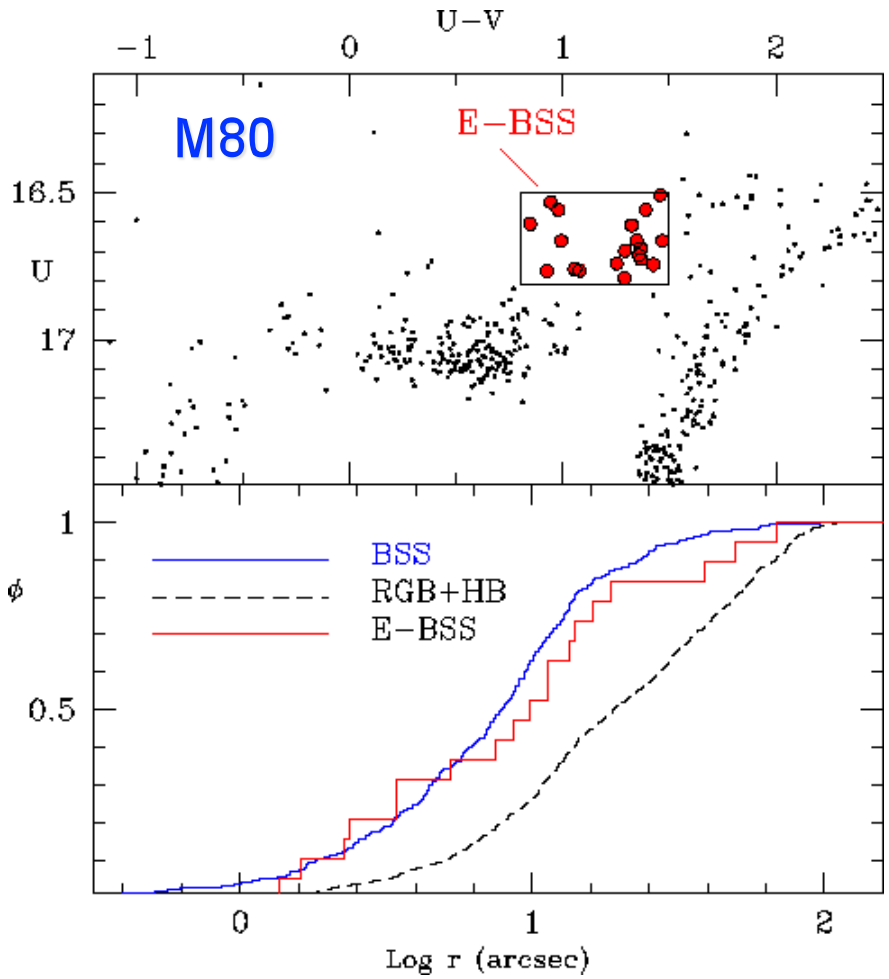
Stage 4- rotation decreases and internal mixing reduces the surface CO anomaly

Chemical and kinematical data are now available for a few additional clusters:

Alessio (chemistry) and Loredana (kinematics) will present the new results in a few minutes

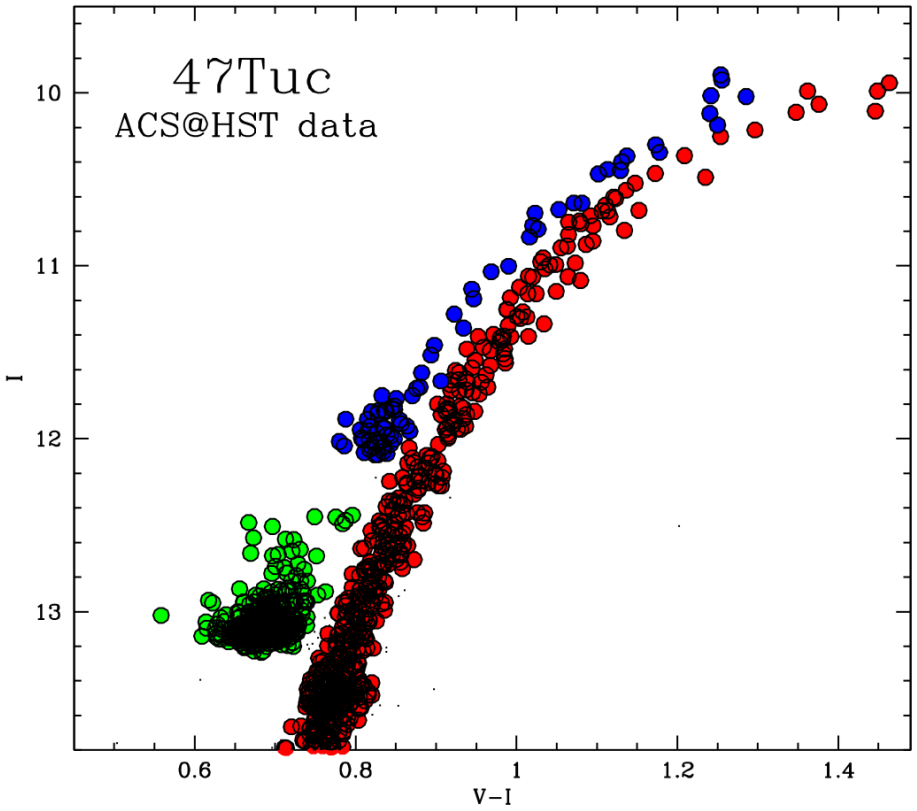
Searching for Evolved BSS



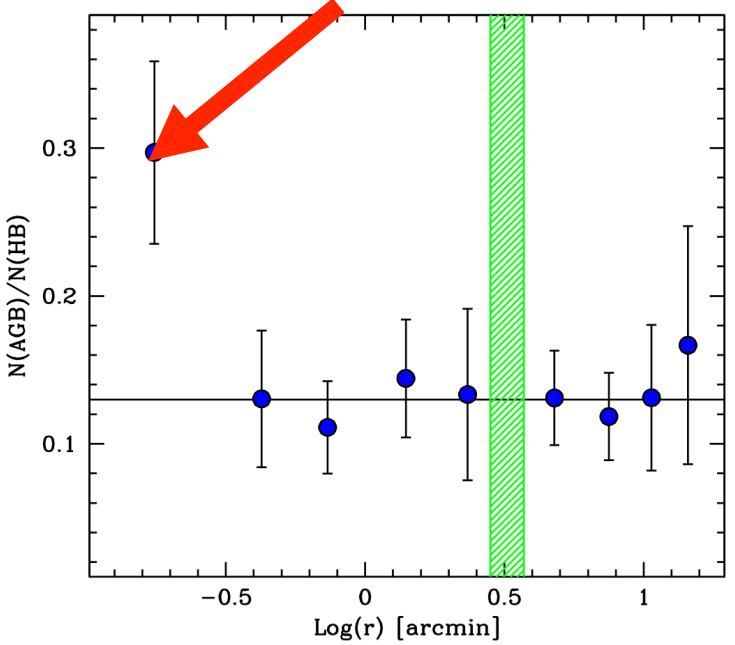


19 *E-BSS* candidates

Evolved BSS in the AGB of 47 Tuc?



Contamination by non genuine low-mass AGB ???



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

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The End