MODEST 15-S

Kobe, Japan, Dec 7-11, 2015

シミュレーションが未来をひらく
理化学研究所 計算科学研究機構
RIKEN Advanced Institute for Computational Science

Clocks and Scales to understand the physics of BSS

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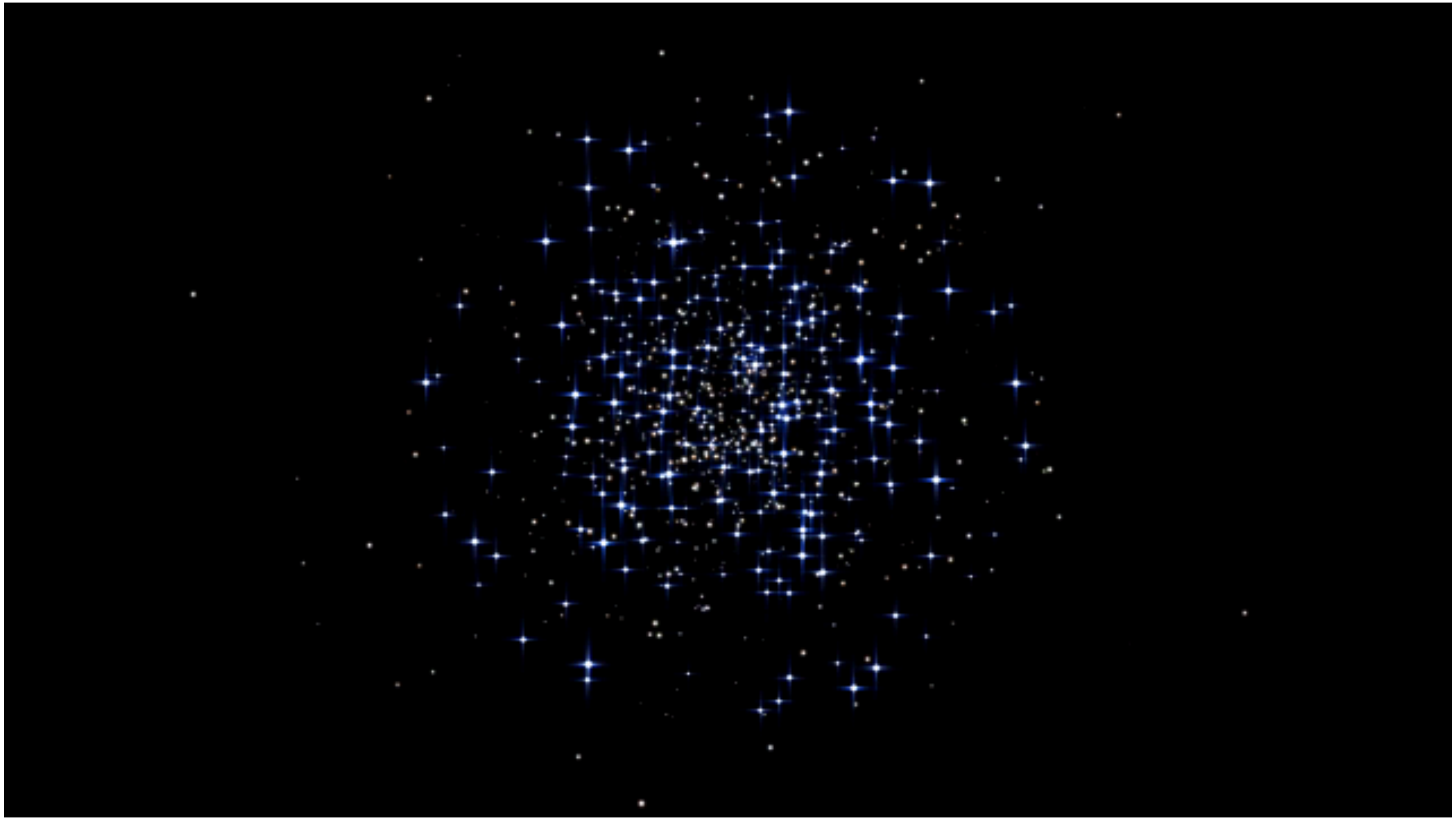
Kobe, Japan, December 8, 2015

Cosmic-Lab

- 5-year project (web site at **www.cosmic-lab.eu**)
- *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

WHY GCs?



GCs are the only stellar systems able to undergo nearly all the physical processes known in stellar dynamics over a time scale significantly shorter than the Hubble time.

This dynamical activity can generate **exotica**

Today I'll talk about CLOCKS and SCALES in the context of understanding the physics of Blue Straggler Stars in GCs

The luminosity/mass at the TO level sets the CHRONOLOGICAL AGE of a Stellar Population (SP)…

but stellar systems with the same chronological age can have reached quite different stages of dynamical evolution (they have different DYNAMICAL AGE)

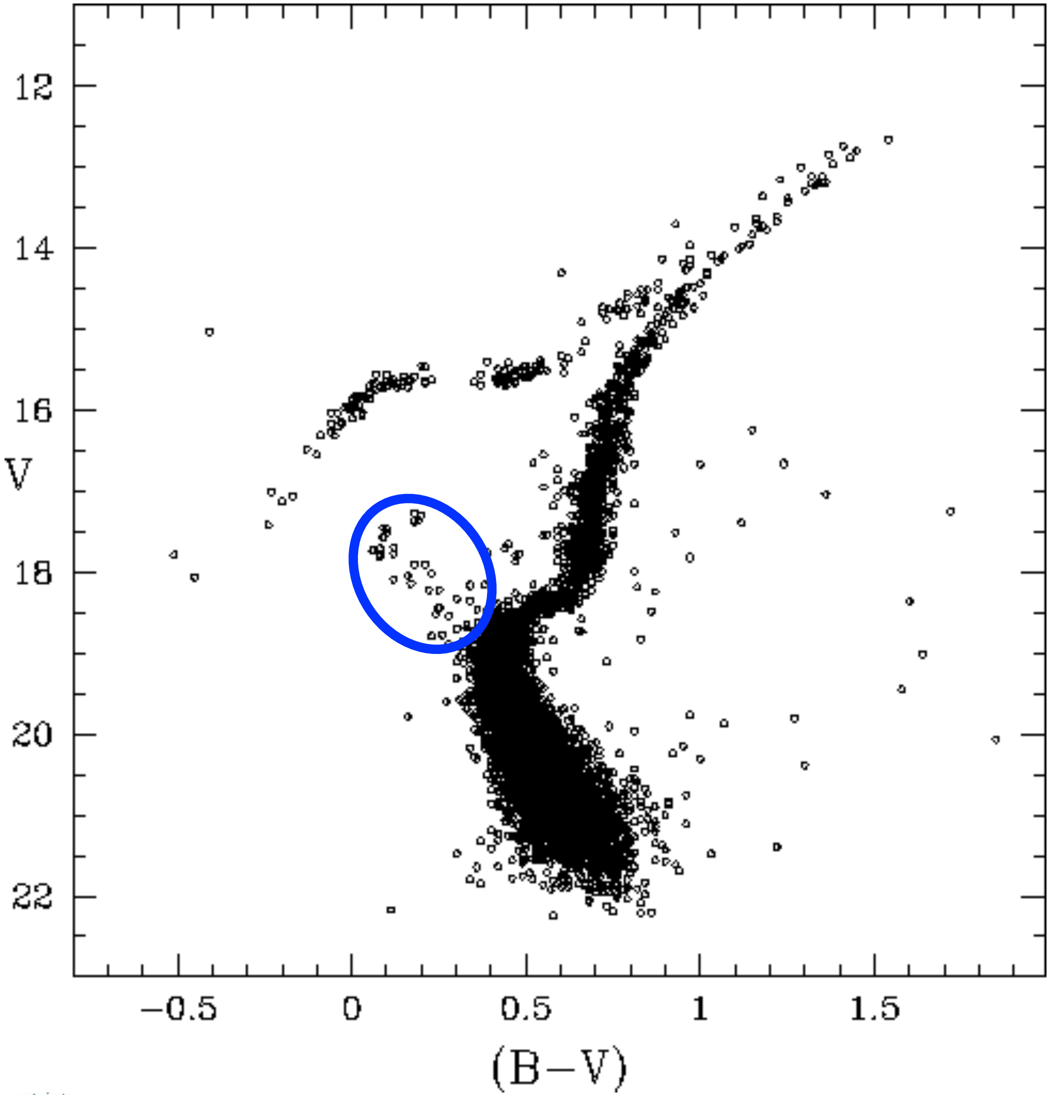
In order to properly characterize a SP we need to know both:

the CHRONOLOGICAL

& the DYNAMICAL ages

Blue Straggler Stars (BSS)

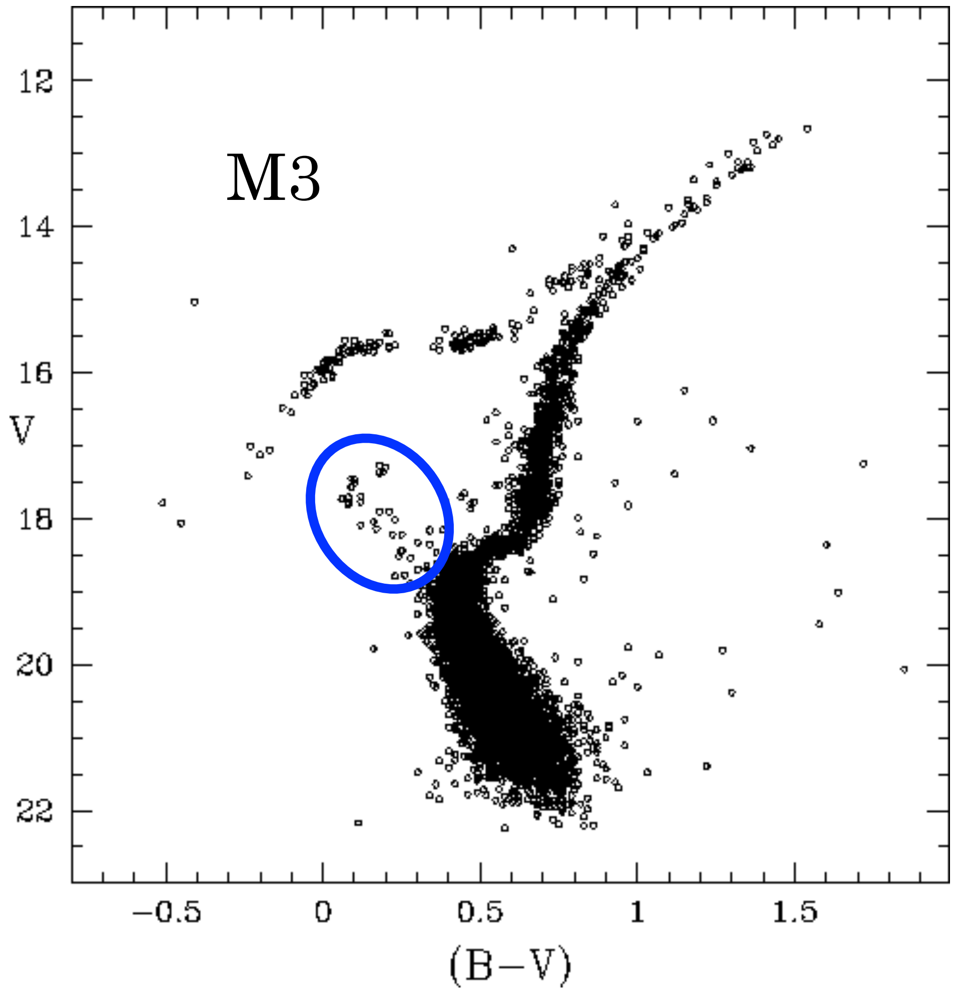
A PECULIAR stellar population



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

Their existence CANNOT be interpreted in terms of the evolution of a "normal" single star

Blue Straggler Stars (BSS)

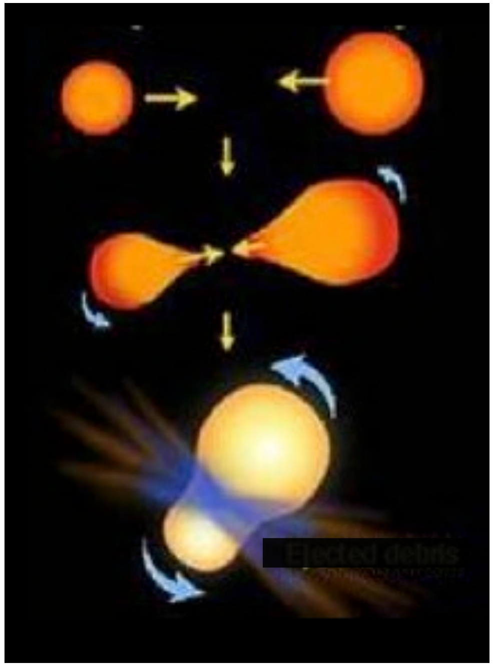


They LOOK younger but they are OLD stars rejuvenated by dynamical processes

Merger of two low-mass stars

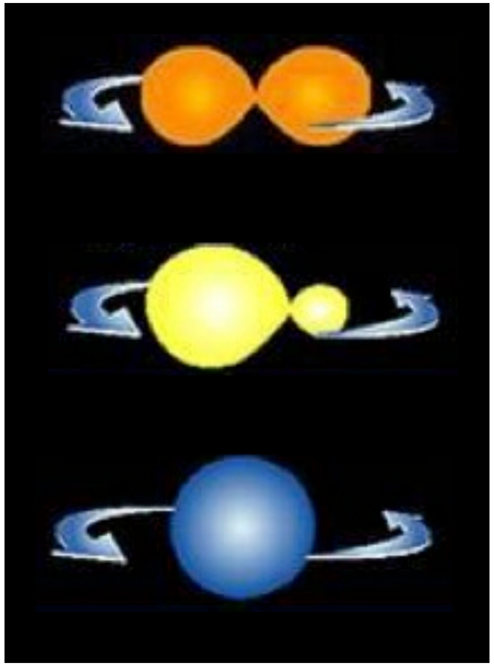
The formation mechanisms

COLLISIONS



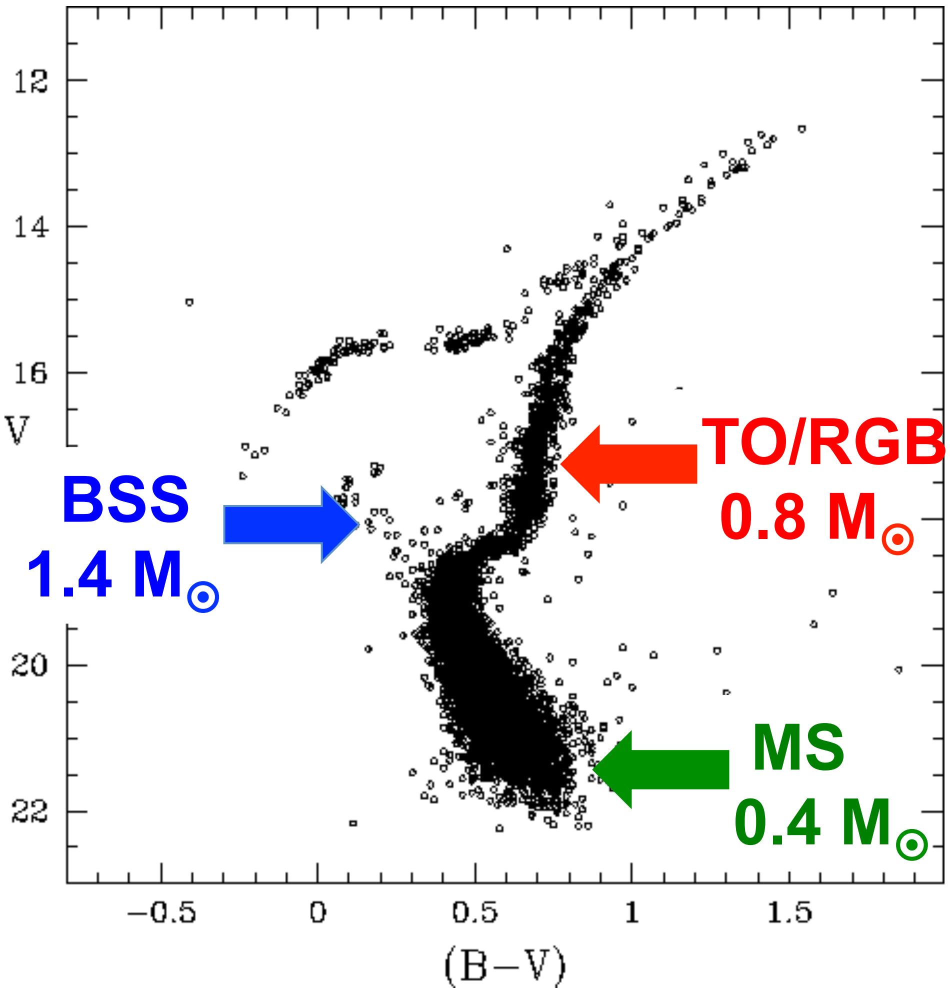
depend on **collision** rate
(Hills & Day 1976)

MASS-TRANSFER



depend on **binary fraction + dynamical interactions** and stellar evolution (McCrea 1964)

Blue Straggler Stars (BSS)



BSS
more massive
than normal stars

(see also Shara et al. 1997, Fiorentino et al 2014)

They are crucial gravitational probe-particles to test GC internal dynamical processes

BSS are heavy stars ($M_{BSS} = 1.2\text{-}1.4\ M_\odot$) orbiting a "sea" of "normal" light stars ($M_{mean} = 0.4\ M_\odot$): they are subject to **dynamical friction** that progressively makes them sink toward the cluster center

The **df** time-scale depends on:

(1) Star mass **(2) Local cluster density**

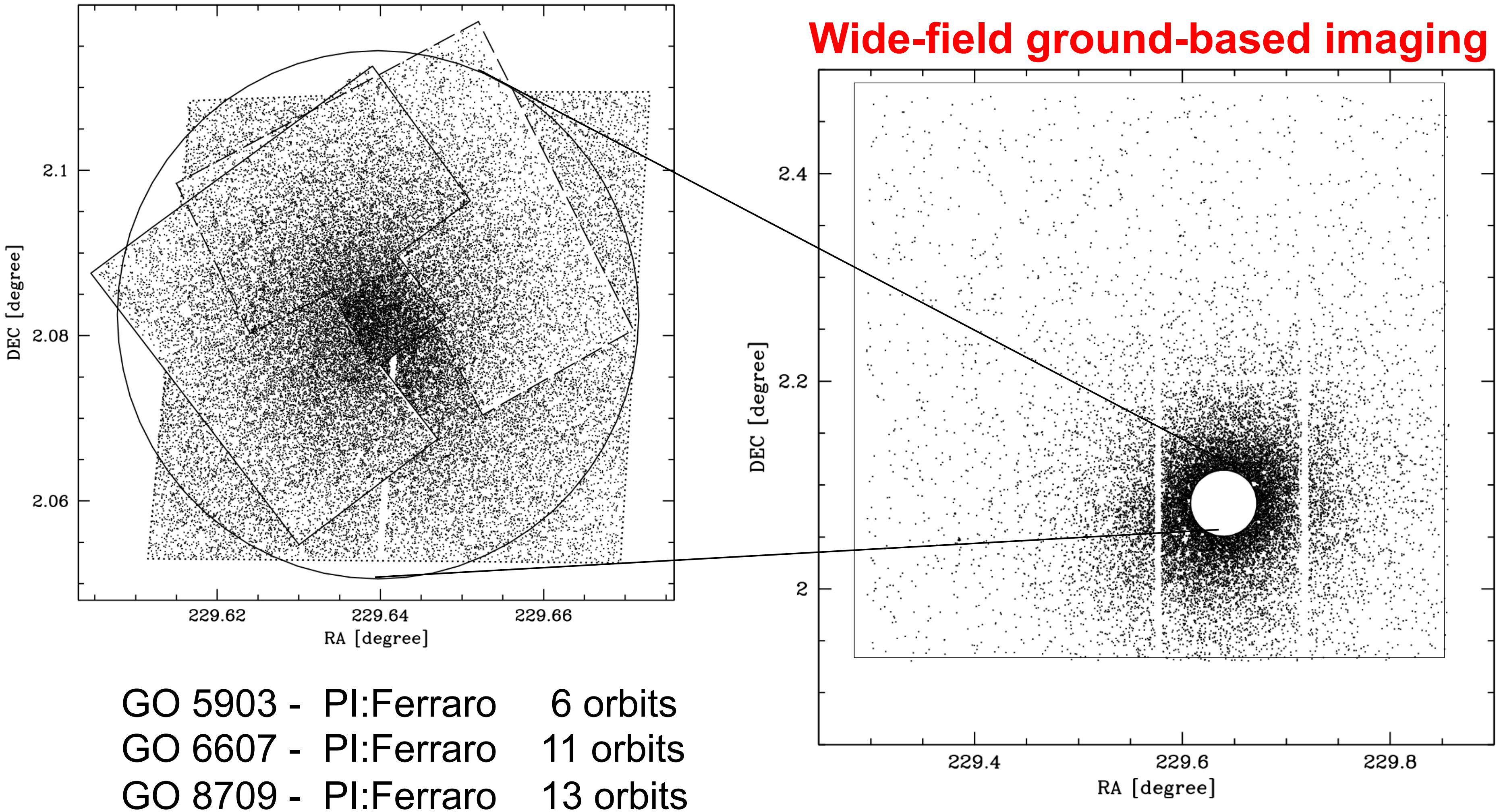
$$t_{df} \approx \frac{1}{M_{BSS}\ \rho(r)}$$

Because of this, **df** is expected to affect, first, the most internal BSS and then BSS progressively **at larger and larger distances,** as function of time

What we need to know is the radial distribution of these heavy objects alongthe entire cluster extension

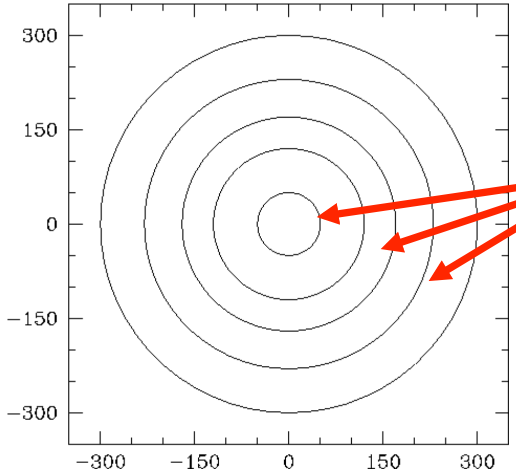
High-res: HST/WFPC2+ACS

Wide-field ground-based imaging



GO 5903 - PI:Ferraro 6 orbits
GO 6607 - PI:Ferraro 11 orbits
GO 8709 - PI:Ferraro 13 orbits
GO10524 - PI:Ferraro 11 orbits
GO11975 - PI:Ferraro 177 orbits
GO12516 - PI:Ferraro 21 orbits
Grandtotal 239 orbits

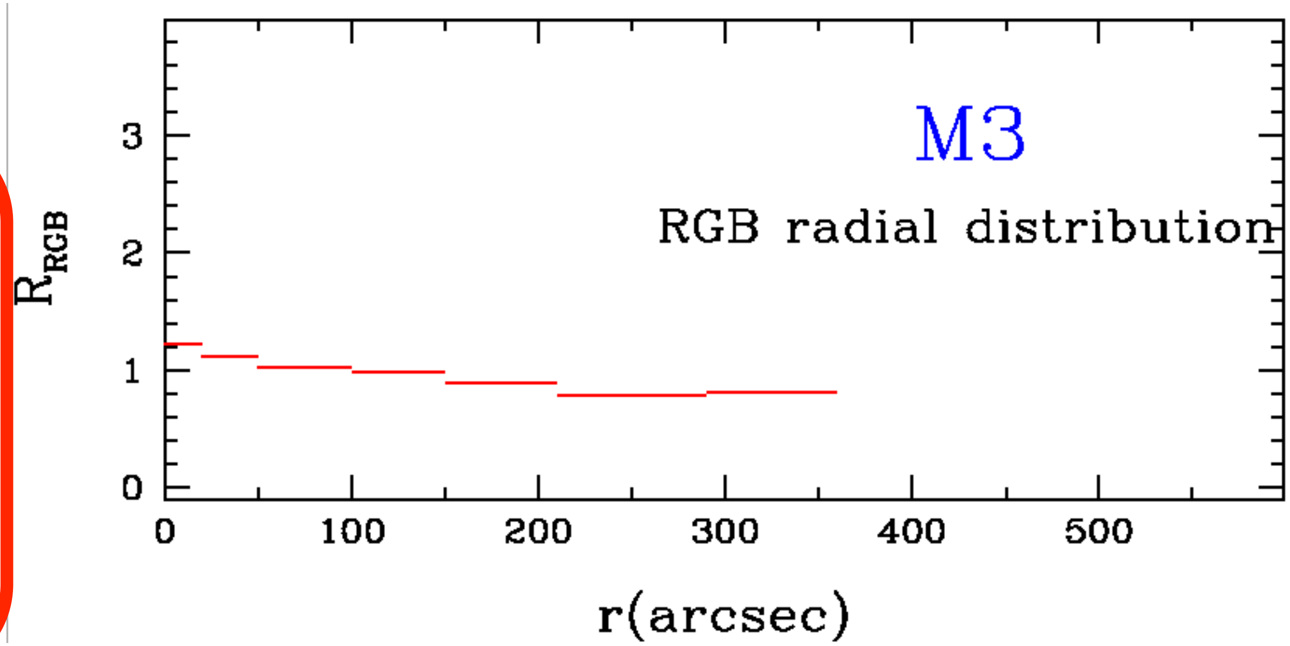
THE BSS RADIAL DISTRIBUTION



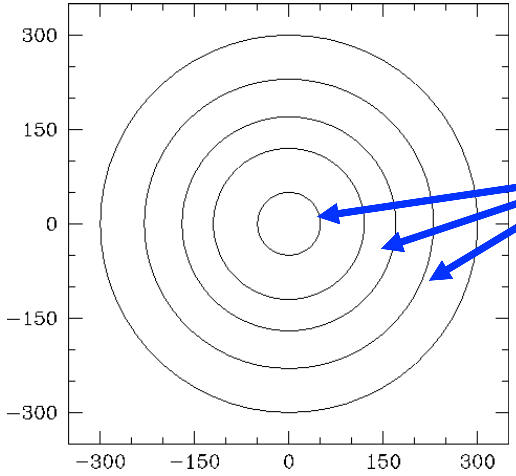
$$R_{RGB} = \frac{N_{RGB}/N_{RGB,TOT}}{L_{samp}/L_{TOT}}$$

This quantity is expected to be =1 for any not segregated SP

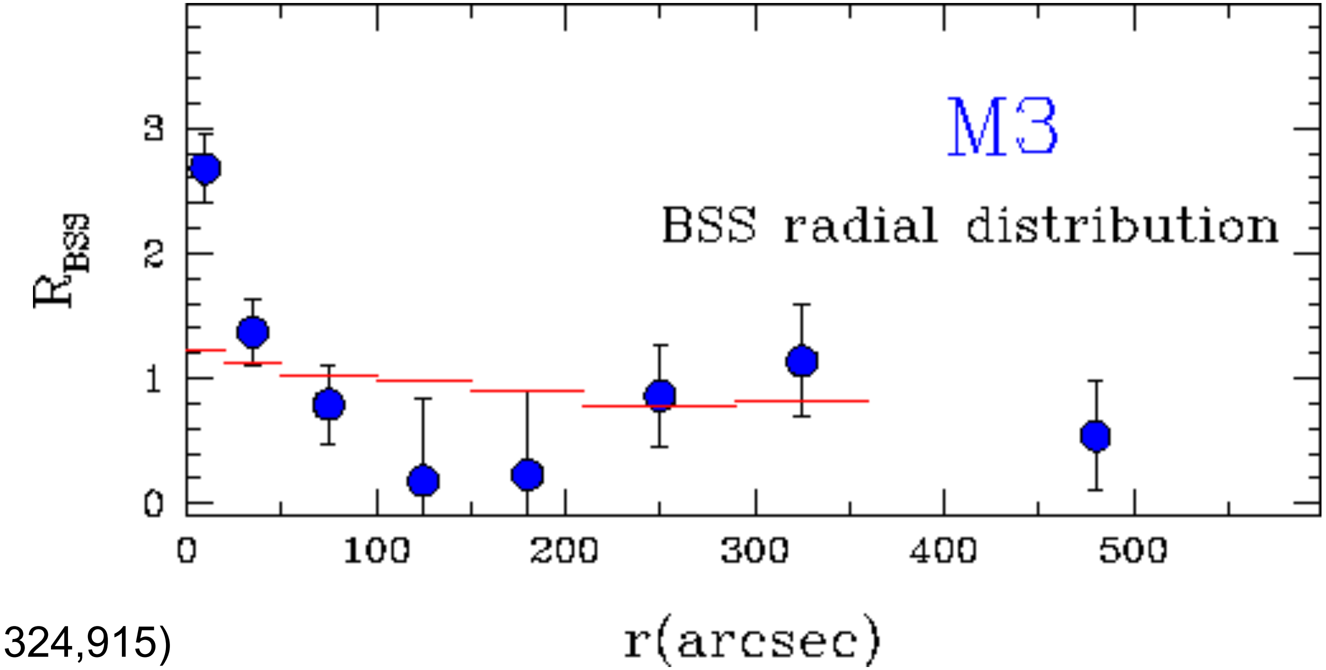
Note that ***a flat distribution*** in this plot means that ***"the number of stars in each annulus exactly scales with the cluster light sampled by each annulus"***



THE BSS RADIAL DISTRIBUTION



$$R_{BSS} = \frac{N_{BSS}/N_{BSS,TOT}}{L_{samp}/L_{TOT}}$$

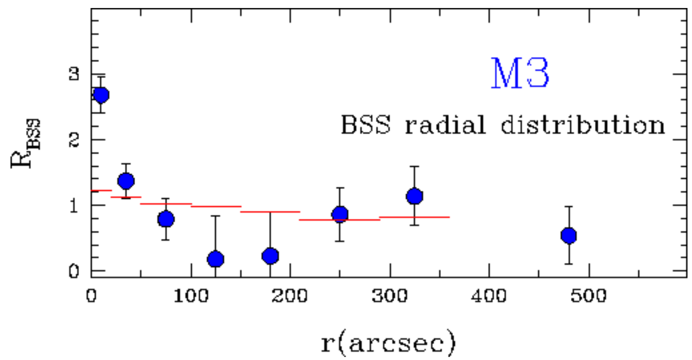


Ferraro et al (1997,A&A,324,915)

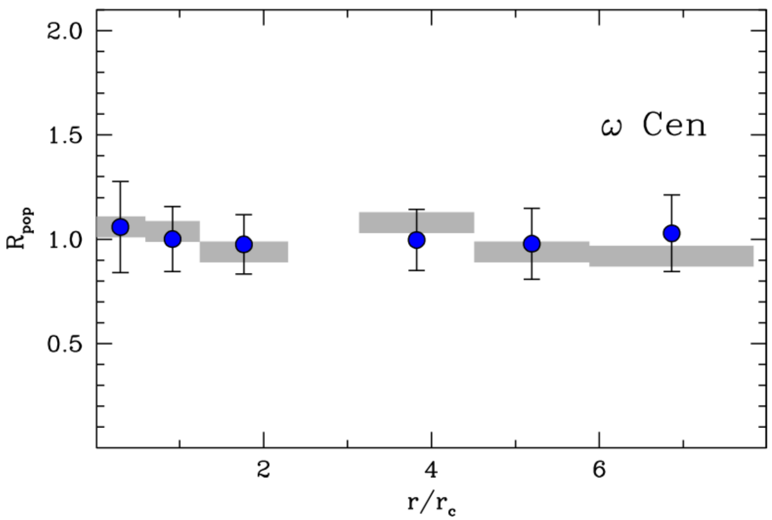
BSS radial distribution

Over the last 15 years we studied the BSS radial distribution over the entire cluster extensions in 25 stellar systems. Finding a variety of cases

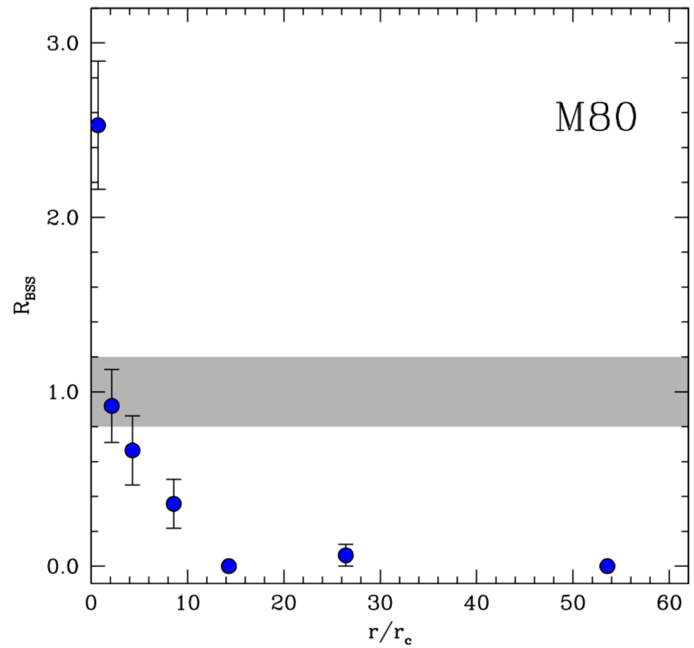
"bimodal"



"Flat"



"Unimodal" (single-peak)



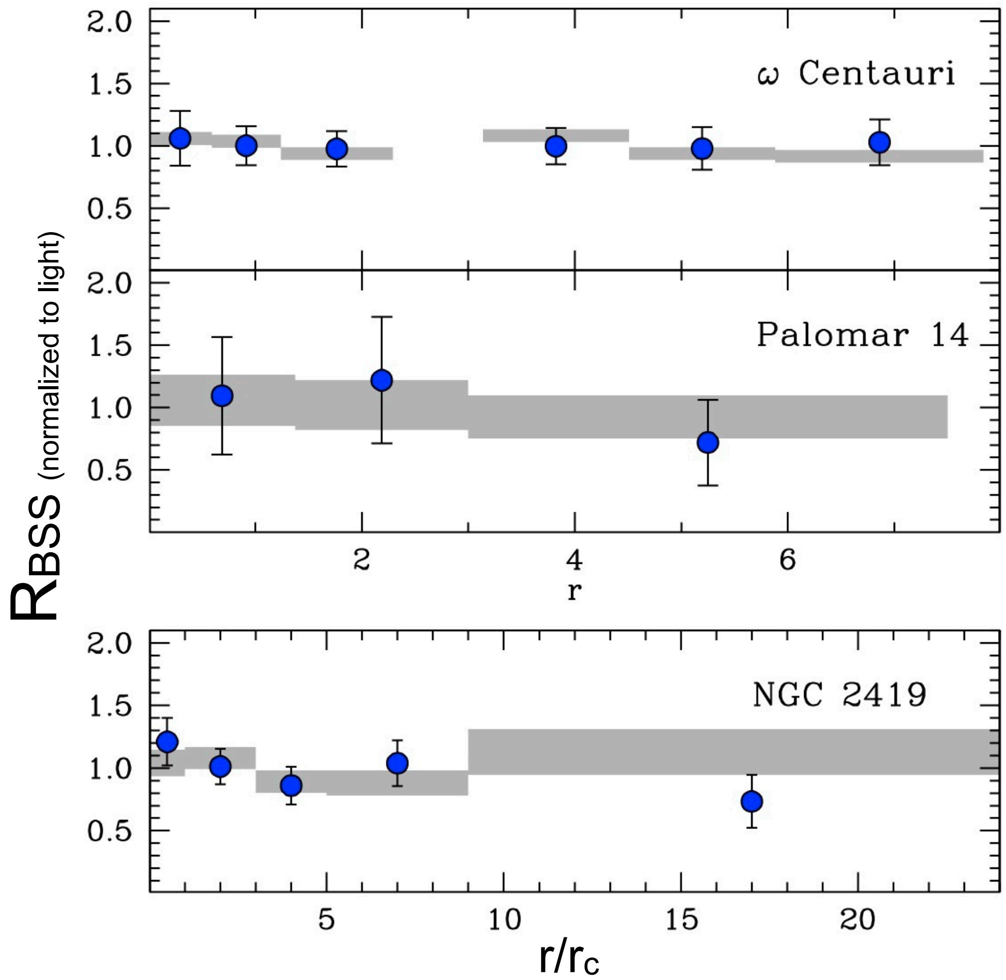
The BSS radial distribution is shaped by dynamical friction, which segregates BSS progressively in time

….. THE DYNAMICAL CLOCK…..

The dynamical clock

Ferraro et al (2012,Nature,492,393)

Family I : FLAT BSS radial distribution



The BSS distribution is **flat** in full agreement with that of "normal stars"

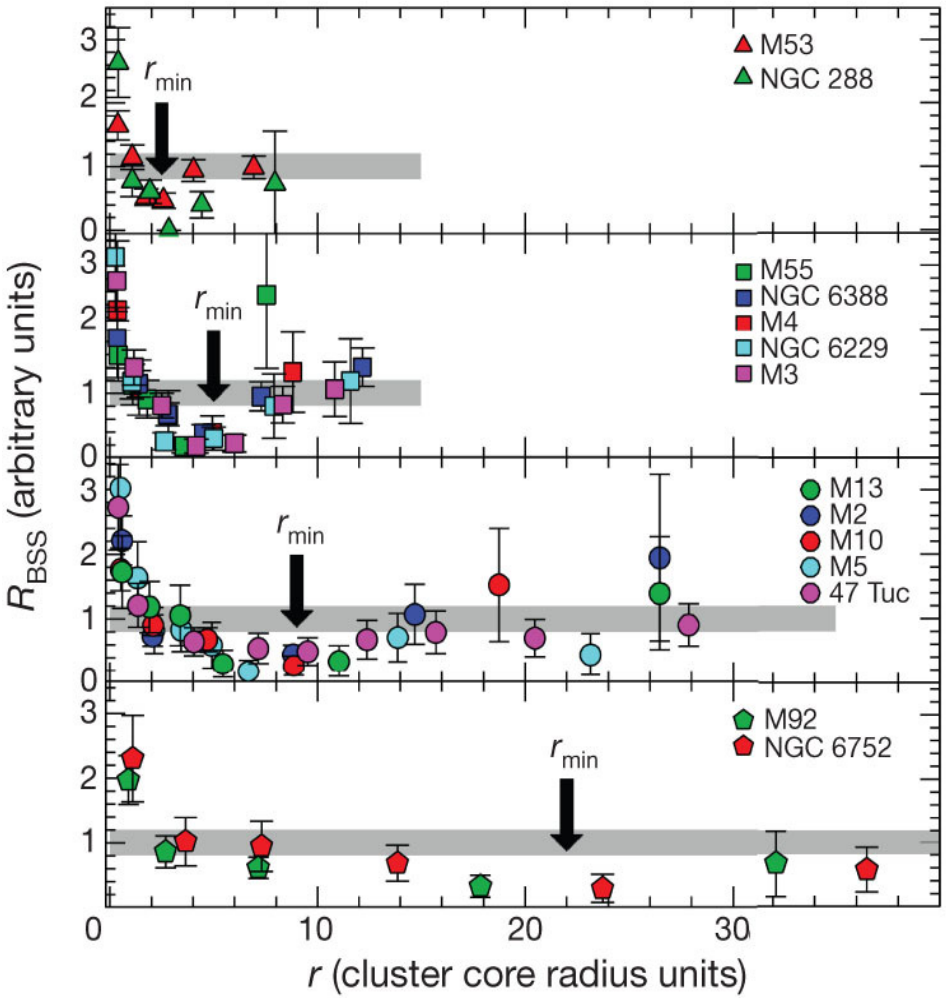
dynamical friction has not affected the BSS distribution yet, not EVEN in the cluster center

Family I: the dynamically YOUNG clusters

The dynamical clock

Ferraro et al (2012,Nature,492,393)

Family II: bimodal BSS radial distribution



The BSS distribution is **bimodal** but the minimum is found at different distances from the cluster center

df is effective in segregating BSS, starting from those at shorter distances from the cluster center

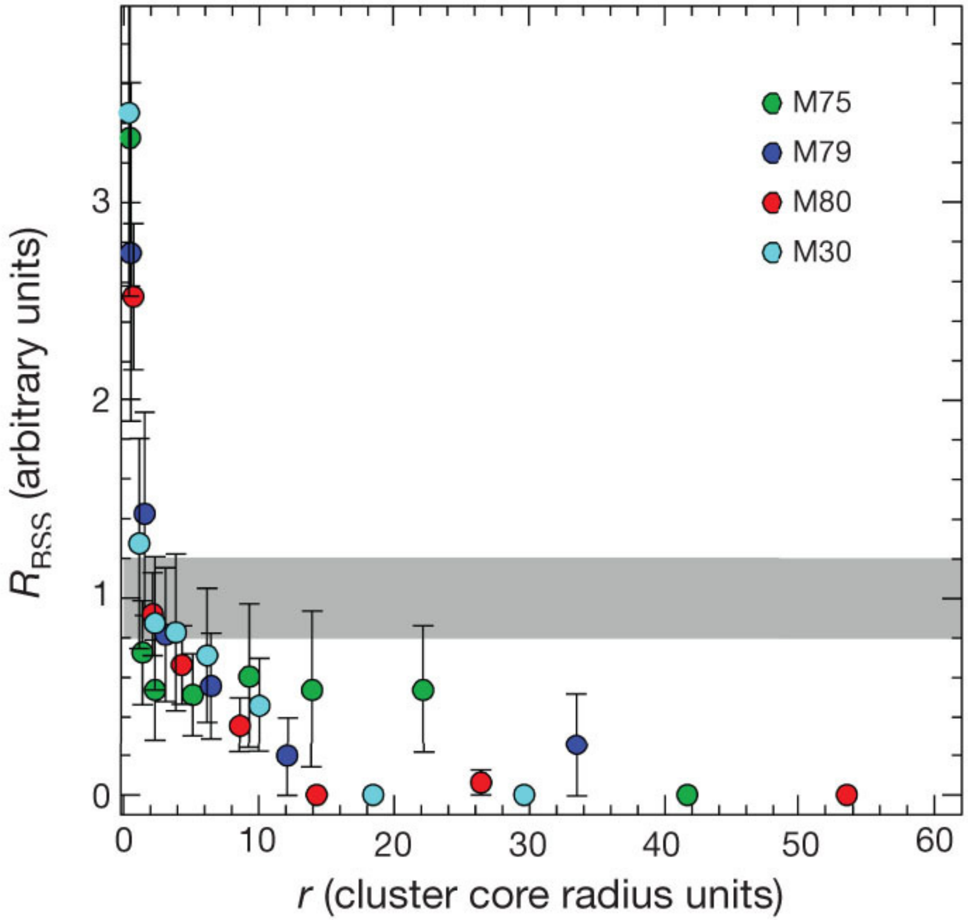
The action of **df** extends progressively at larger distances from the cluster center = the minimum is moving progressively outward

Family II: the dynamically INTERMEDIATE-age clusters

The dynamical clock

Ferraro et al (2012,Nature,492,393)

Family III: unimodal BSS radial distribution



The BSS distribution is **unimodal** with a well defined peak at the cluster center but no rising branch

df has segregated ALL the BSS, even the most remote ones. The external rising branch disappears.

The action of **df** extended out to the cluster tidal radius

Family III: the dynamically OLD clusters

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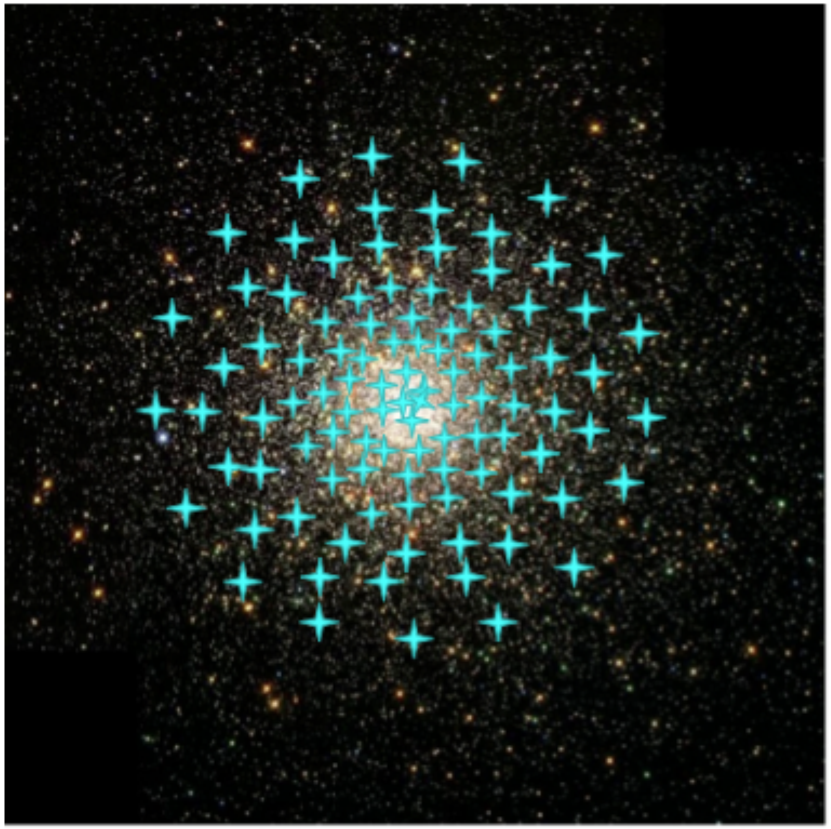
The dynamical clock

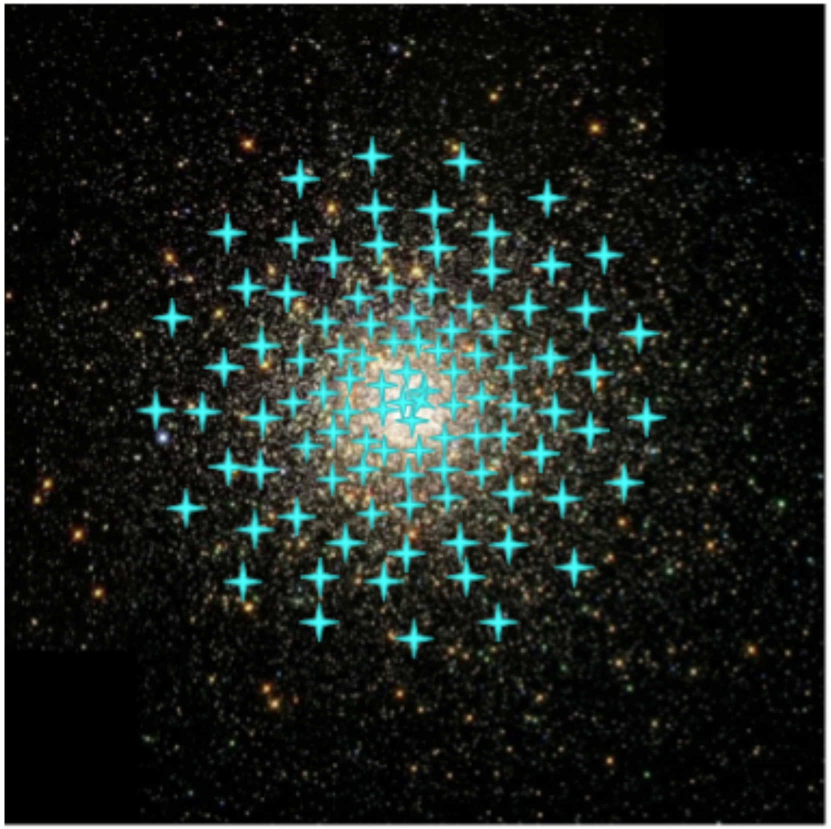
Ferraro et al (2012,Nature,492,393)



The cartoon illustrates the action of **df** that progressively segregates the BSS toward the cluster center producing a dip in the radial distribution that propagates toward the external region as a function of the time.

The dynamical clock

Ferraro et al (2012,Nature,492,393)



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The dynamical clock

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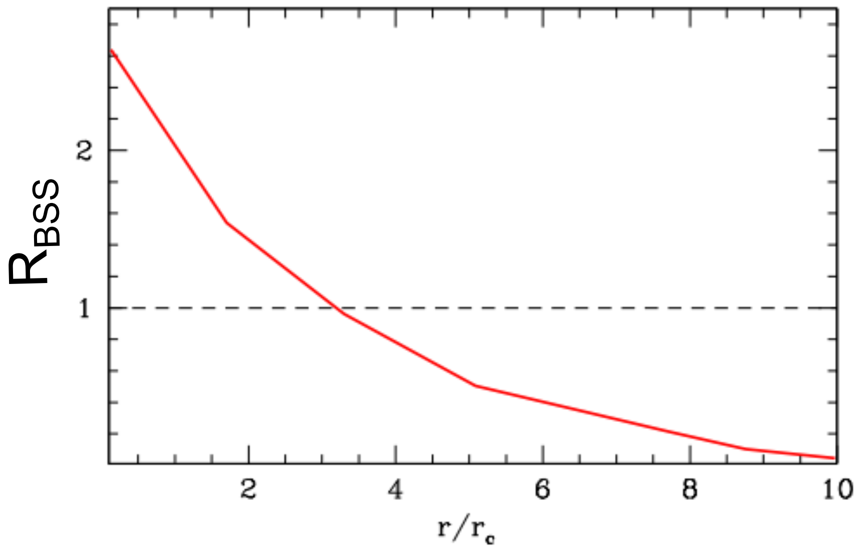
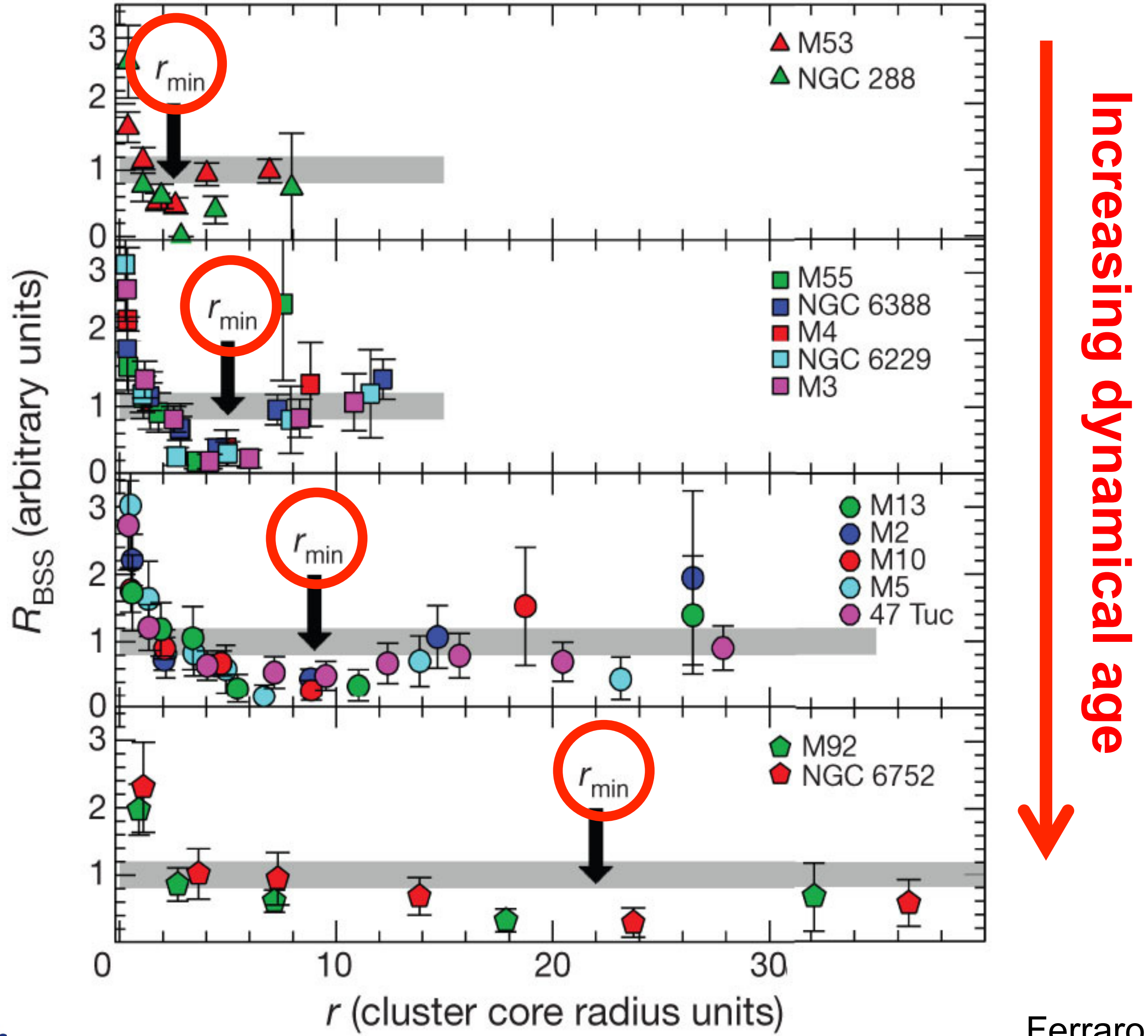


As the engine of a chronometer advances a clock-hand to measure the flow of time, in a similar way dynamical friction moves the minimum outward measuring the dynamical age of a stellar system

The position of the minimum is **THE HAND** of the **DYNAMICAL CLOCK**



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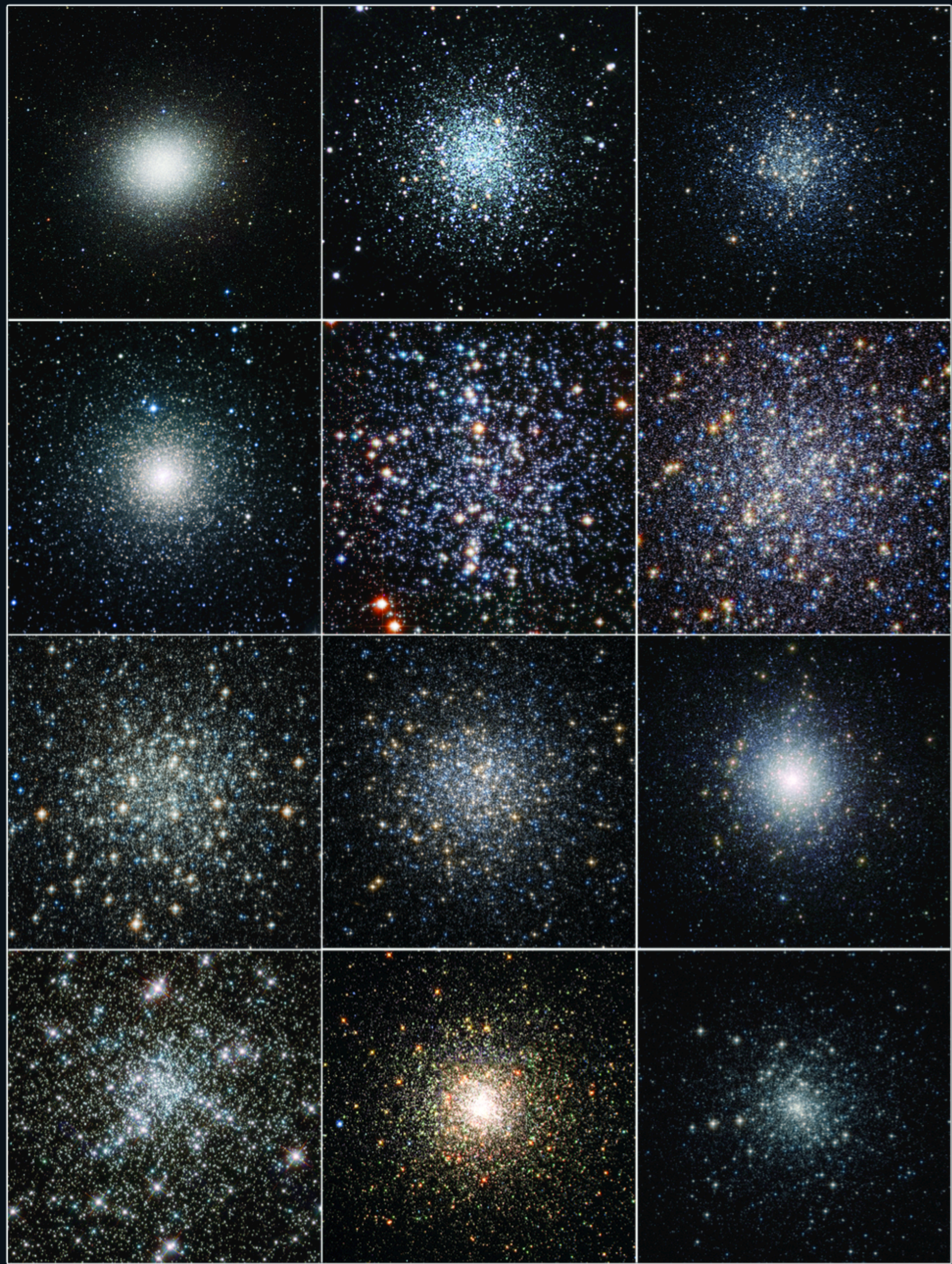
Ferraro et al 2012, Nature,492,393

THE DYNAMICAL CLOCK

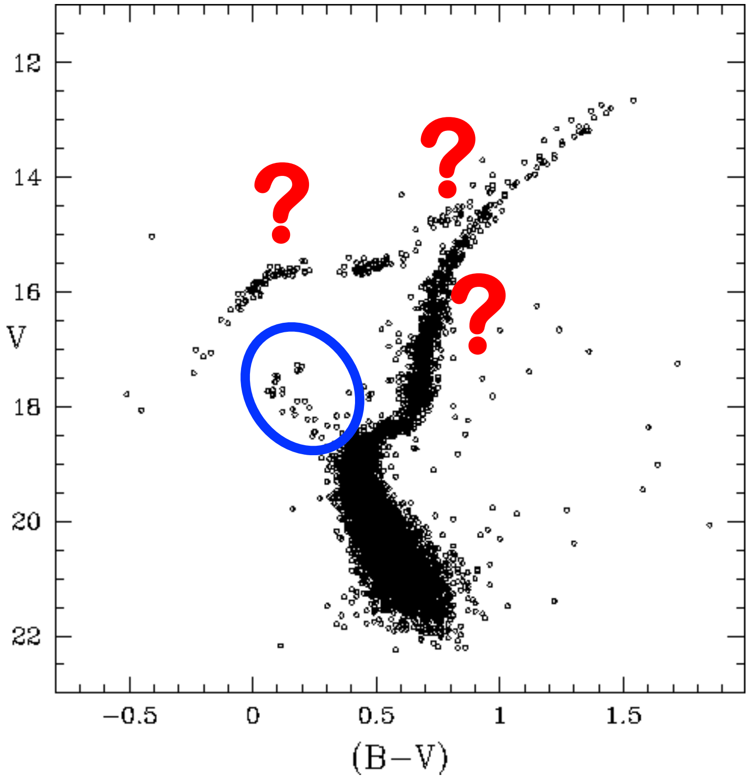
young

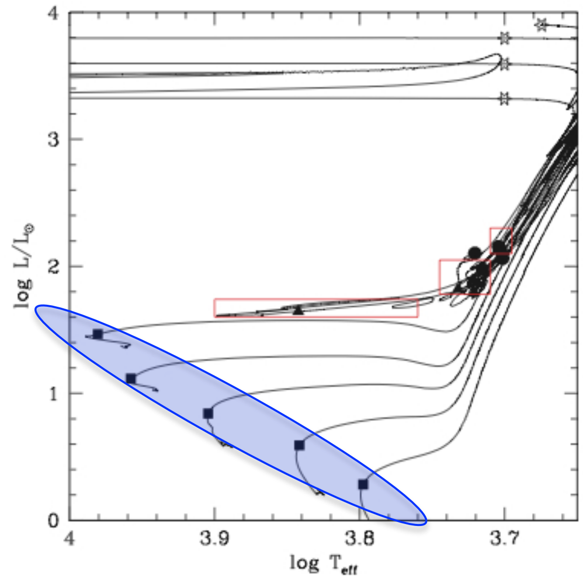


old

The E-BSS search in GCs

As their normal sisters, BSS are expected to evolve outside the MS and to experience all the post-MS evolutionary phases.

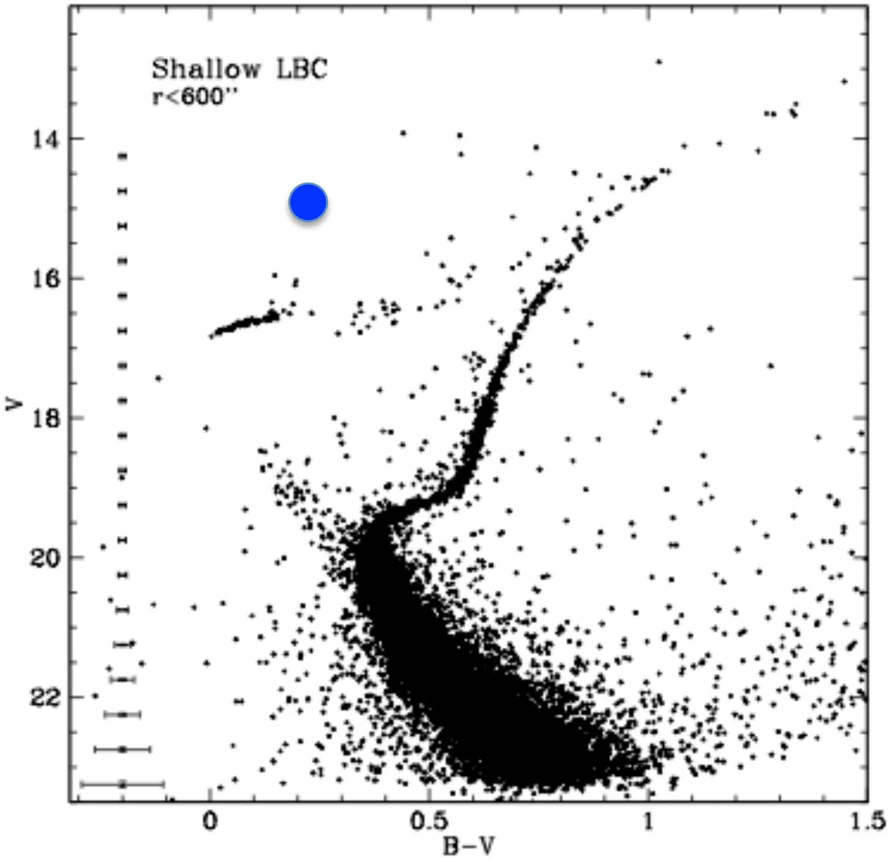




However, while BSS are easily identifiable during the MS stage, E-BSS turns out to be photometrically indistinguishable from the other genuine low-mass stars in the post-MS phases. This is the reason why, in spite of the long search, clear-cut identifications of E-BSS are still lacking in GCs.

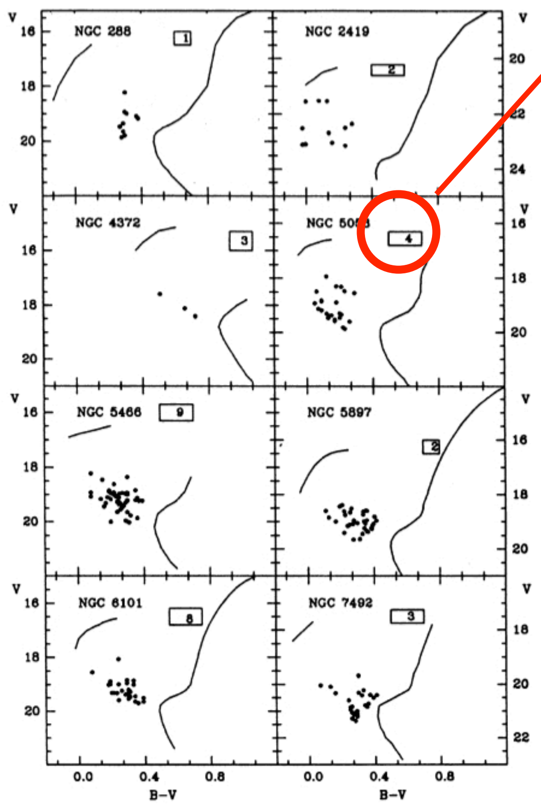
The E-BSS search in GCs

The only EBSS candidate in GCs with an estimated mass is the anomalous Cepheid V19 in NGC5466 (Zinn & Dahn, 1976) with an estimated mass of 1.6 $M_{\odot}$ (Zinn & King 1982)

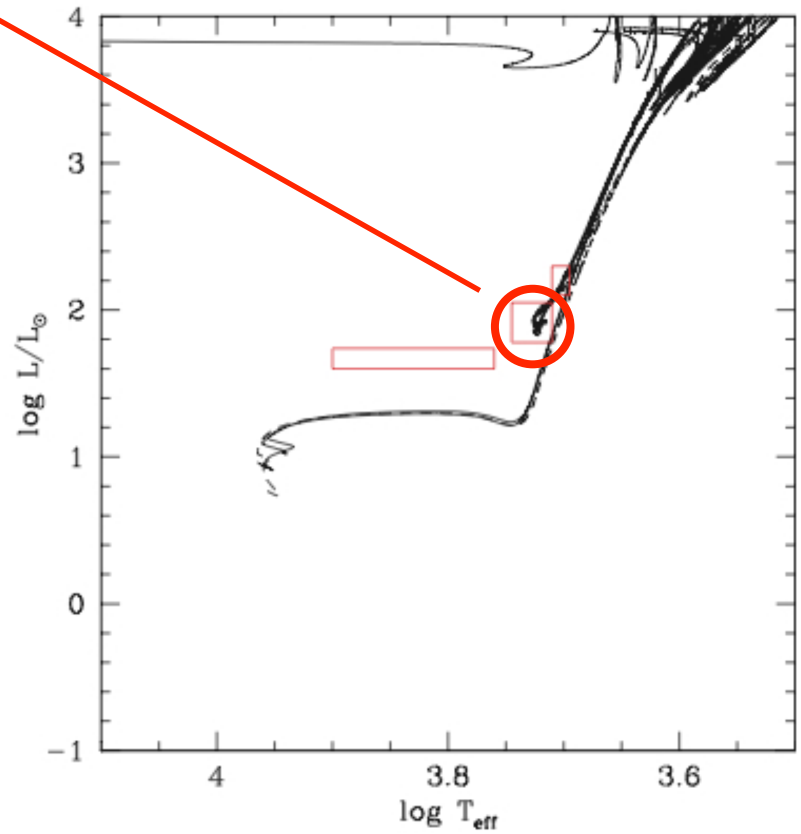


The E-BSS search in GCs

Both observational and theoretical arguments suggest that a **region** located in the CMD between the HB level and the AGB clump is the best place where E-BSS can be identified

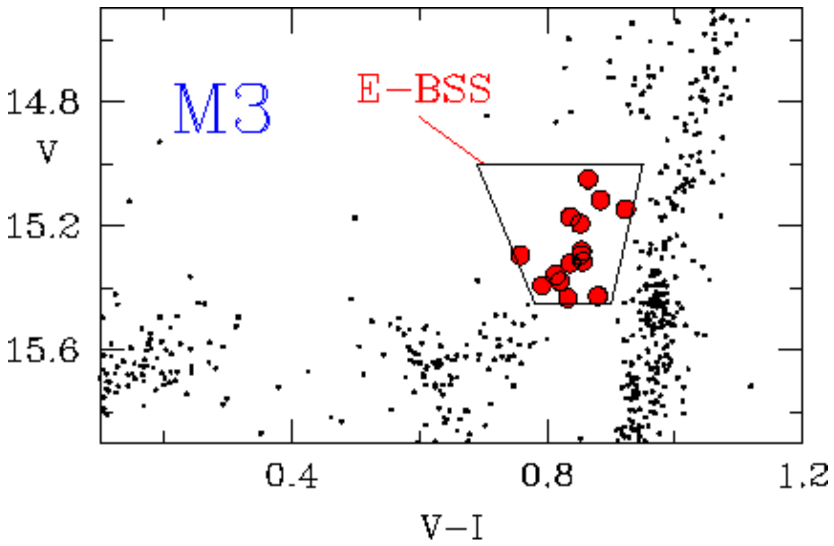


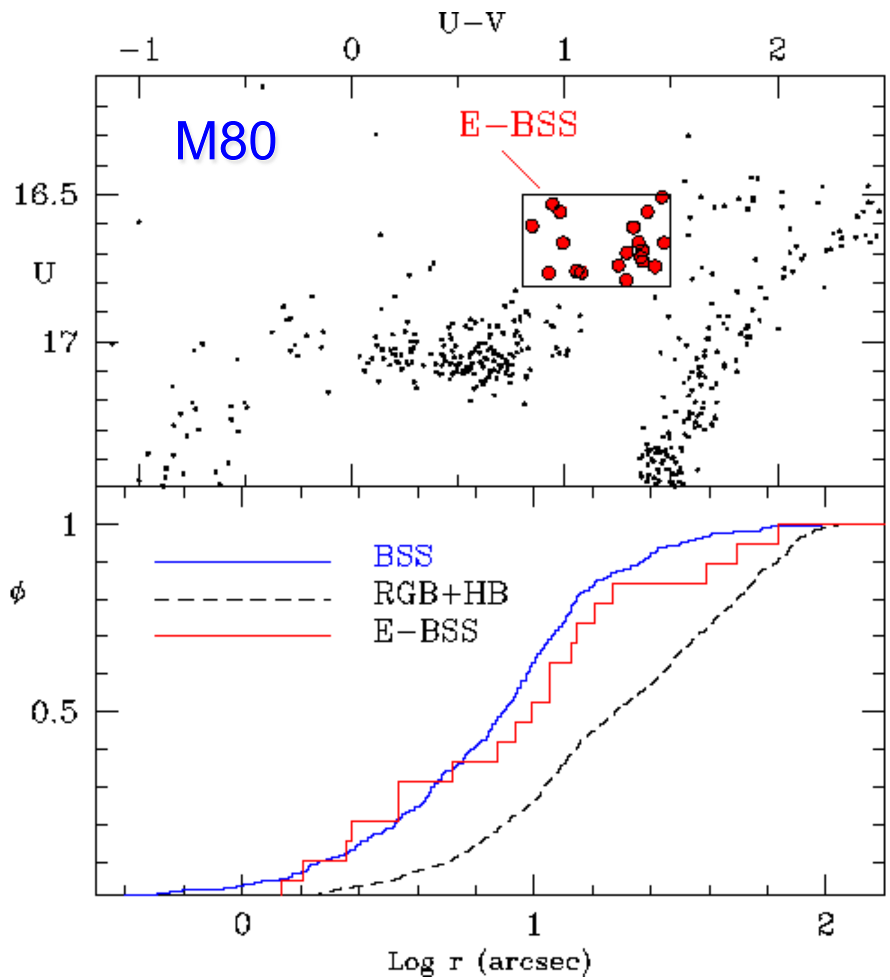
Fusi Pecci et al 1992, AJ,104, 1831



Sills et al 2009, ApJ,692, 1411

The E-BSS search in GCs





19 *E-BSS* candidates

Ferraro et al 1997, A&A, 324, 915
Ferraro et al. 1999, ApJ, 522, 983

A “stellar scale” to search for E-BSS

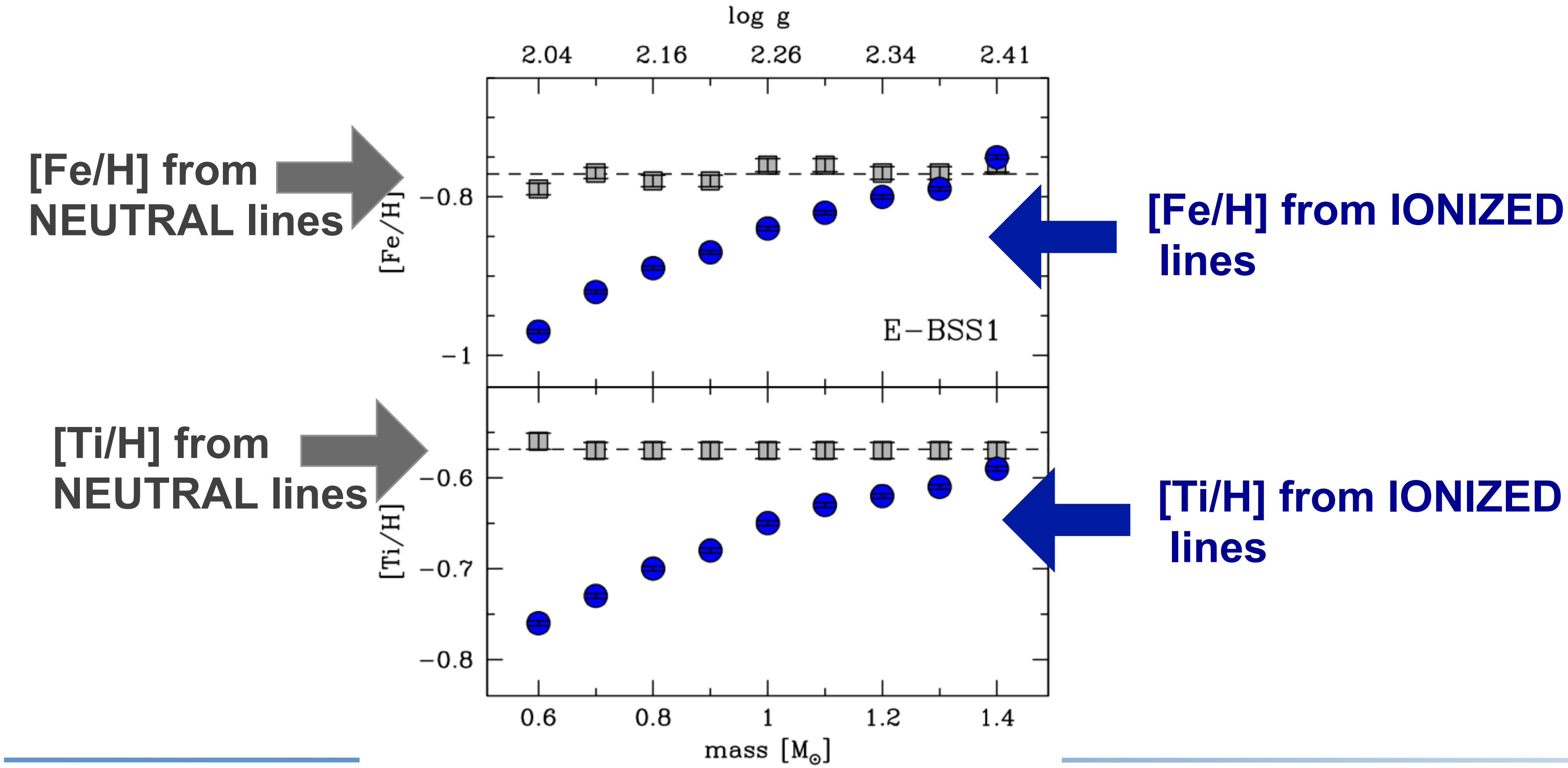
Ferraro et al (2015,arXiv:1512.00649)

Indeed E-BSS appear photometrically indistinguishable from genuine low-mass cluster stars. Hence a tool evidencing their different mass is needed: a “stellar scale”.

A "stellar scale" to search for E-BSS

Ferraro et al (2015,arXiv:1512.00649)

Generally chemical abundances are derived from a combination of neutral and single-ionized absorption lines. However, while abundances obtained from neutral lines are independent of the adopted gravity, the **abundances from ionized absorption lines are quite sensitive to gravity** (mass).



A "stellar scale" to search for E-BSS

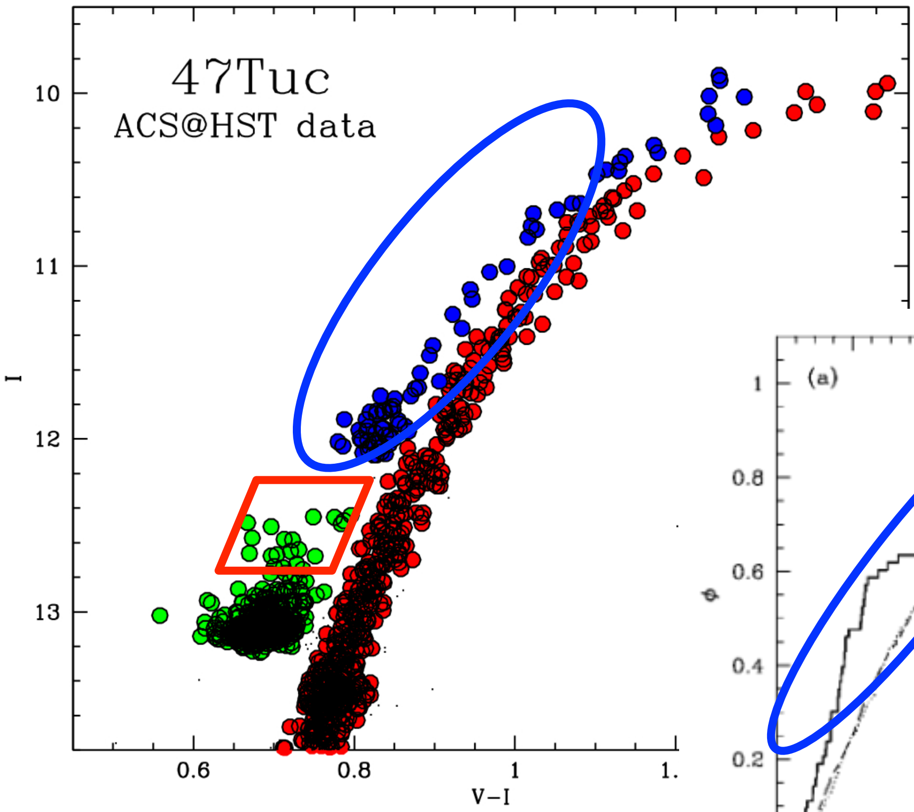
Ferraro et al (2015,arXiv:1512.00649)

Hence the BALANCE between the chemical abundances derived from **neutral** and **ionized** absorption lines can be used to determine the correct gravity of the star (hence its MASS !!).

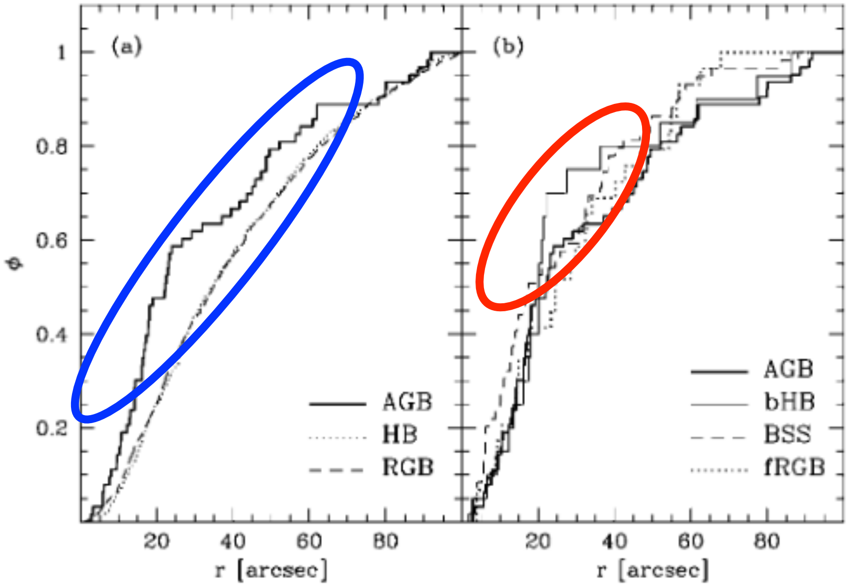
The pointer of such a SCALE is the quantity Δ[Fe/H] = [FeII/H]-[FeI/H].
When the pointer indicates Δ[Fe/H] = 0, then the assumed gravity (mass) is correct

A “stellar scale” to search for E-BSS

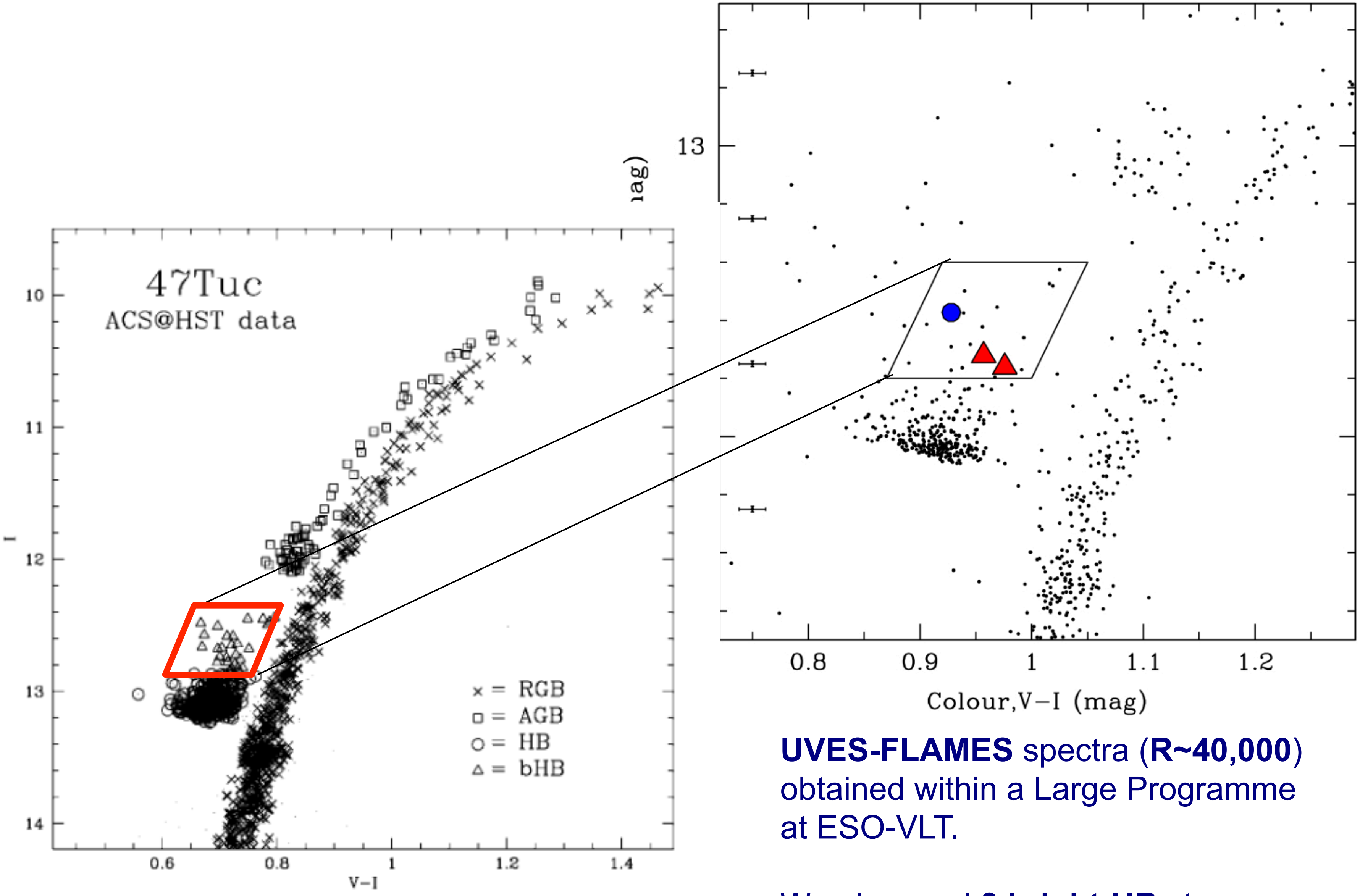
Ferraro et al (2015,arXiv:1512.00649)



In 47 Tuc anomalous radial distributions (suggesting a contamination from non-genuine low-mass stars) were found for both AGB and bright-HB stars



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



Ferraro et al. 2015

UVES-FLAMES spectra (**R~40,000**) obtained within a Large Programme at ESO-VLT.

We observed **3 bright-HB** stars selected in the red box.

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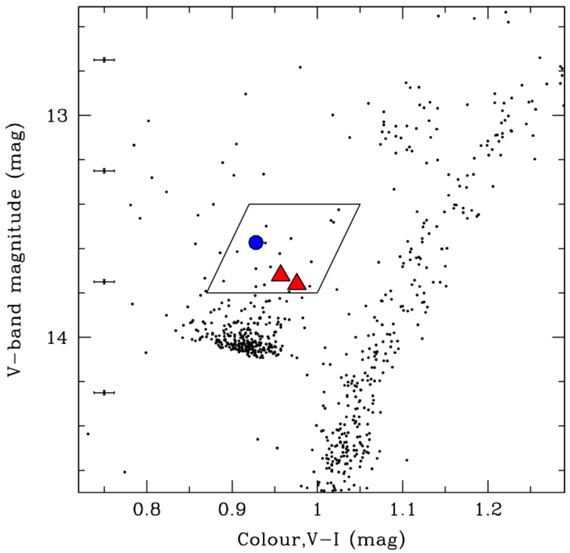
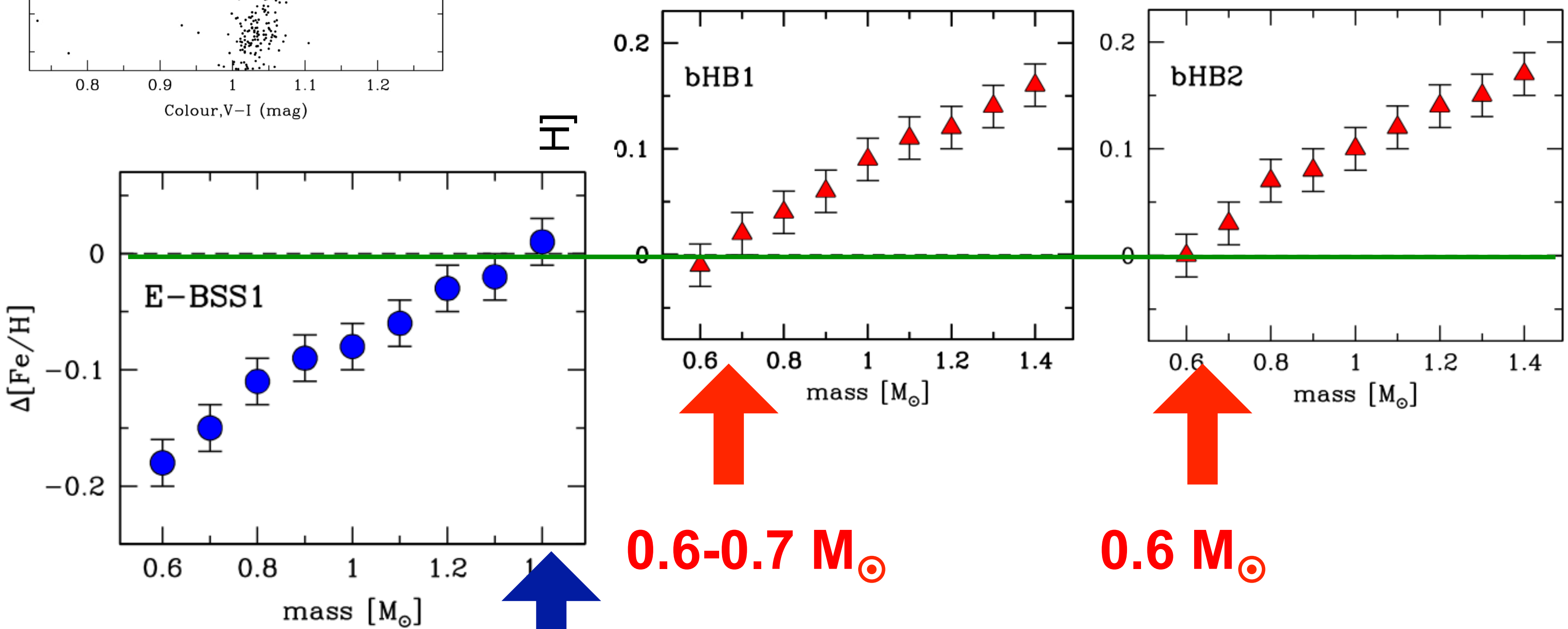
erc

A “stellar scale” to search for E-BSS

Ferraro et al (2015,arXiv:1512.00649)





0.6-0.7 $M_\odot$

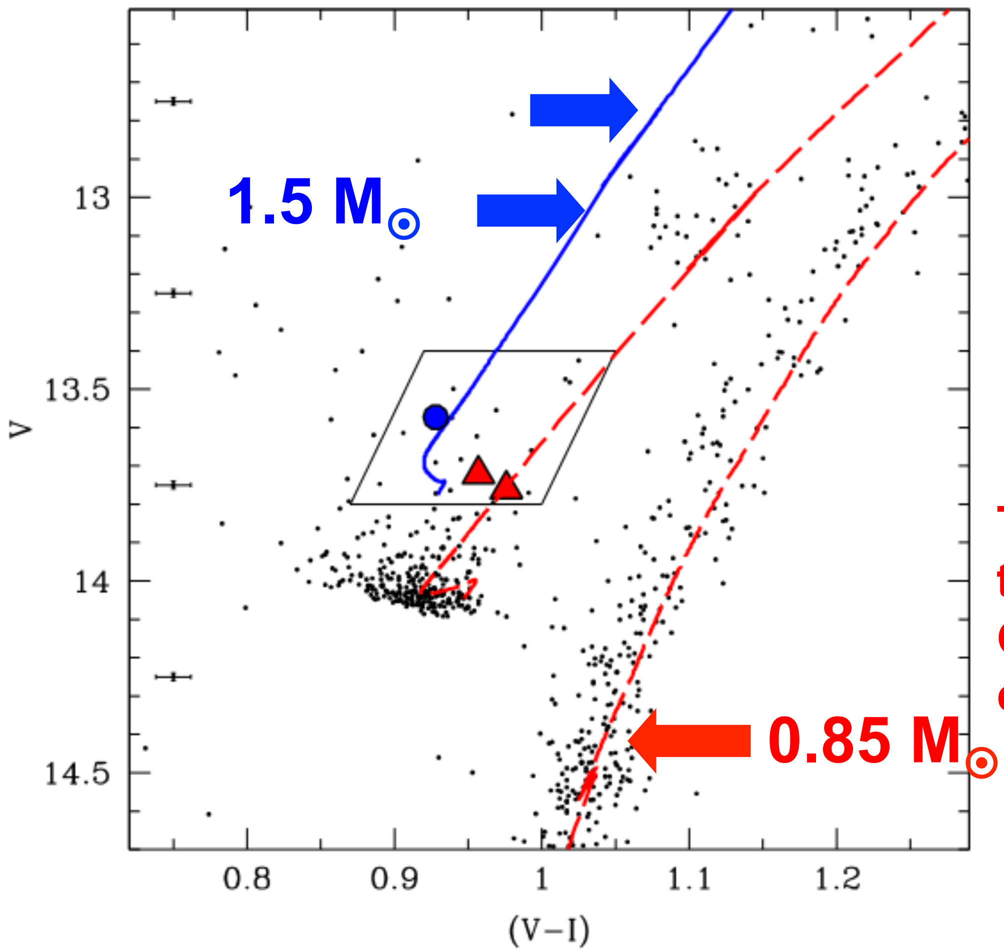
0.6 $M_\odot$

1.4 $M_\odot$!!

EBSS1 turns out to be quite more massive than the other two stars

A "stellar scale" to search for E-BSS

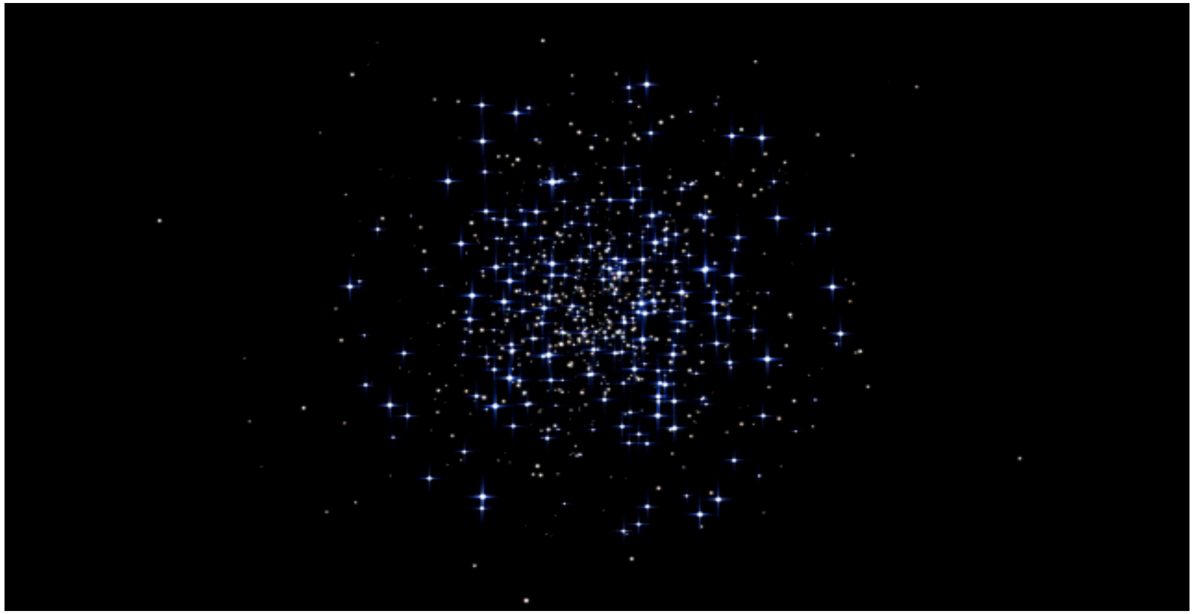
Ferraro et al (2015,arXiv:1512.00649)



Which is the nature of the star E-BSS1?

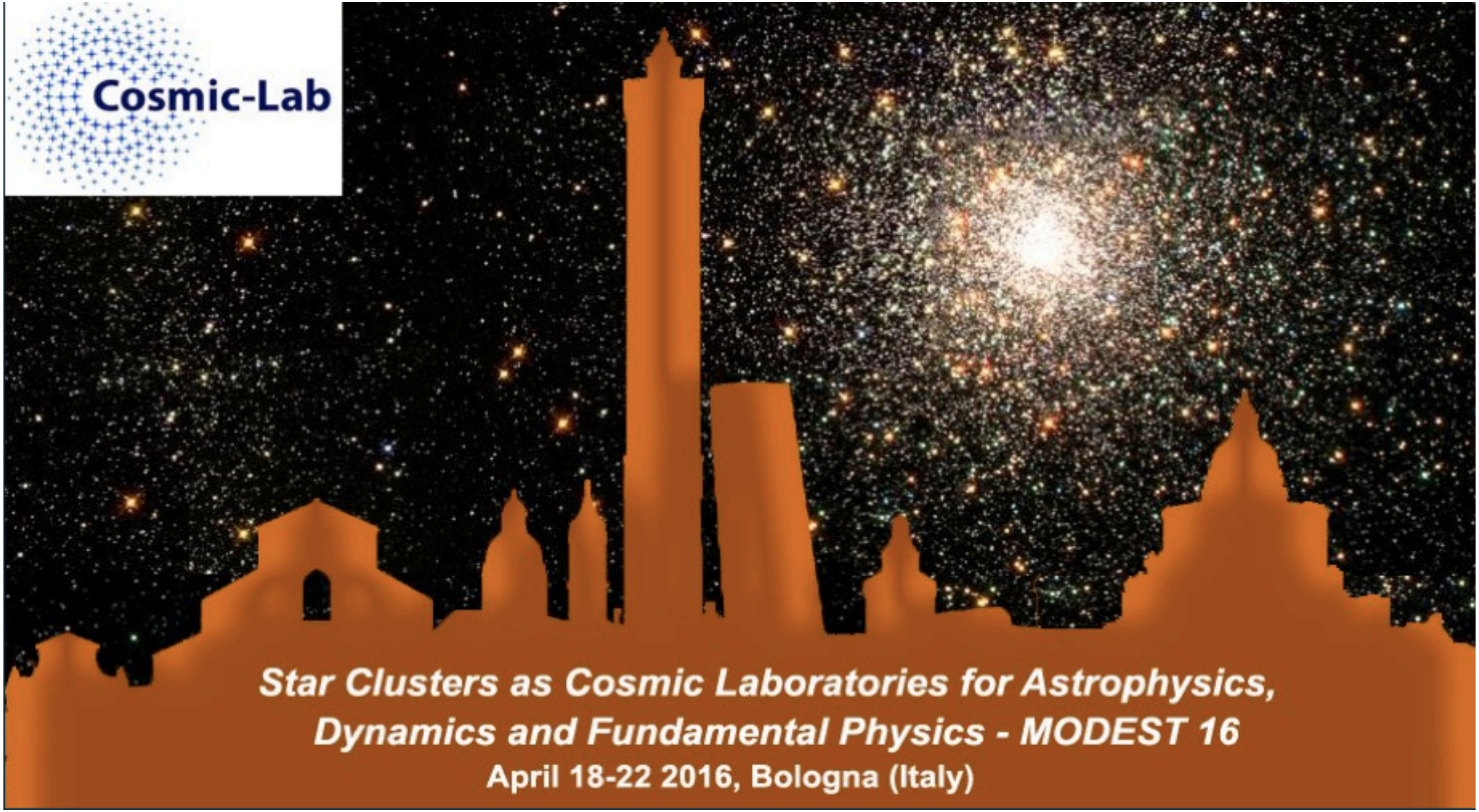
According to its position on the CMD and to the estimated temperature (T = 5000K) and gravity (logg = 2.5 dex), it is probably an **evolved Blue Straggler Star caught during its He-burning phase.**

This identification opens the possibility to start a systematic search of E-BSS in GCs and to determine their chemical/kinematic properties.



BSS are crucial and powerful gravitational test particles.
EBSS are now distinguishable from low-mass sisters

BSS properties (in terms of radial distribution, photometry, etc) trace the past history of the parent clusters
E-BSS can keep memory of their formation mechanism offering us an alternative route to understand the BSS origin…



TOPICS: **Blue Stragglers Stars** **(Intermediate-mass) Black Holes**
Milli-second pulsars **GC dynamics**

Registrations are now open at the web page:

http://www.cosmic-lab.eu/Cosmic-Lab/The_Conference.html

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You can download this presentation from our web-site:

http://www.cosmic-lab.eu/Cosmic-Lab/Presentations.html

The End