Blue Straggler Stars in globular clusters as dynamical probes

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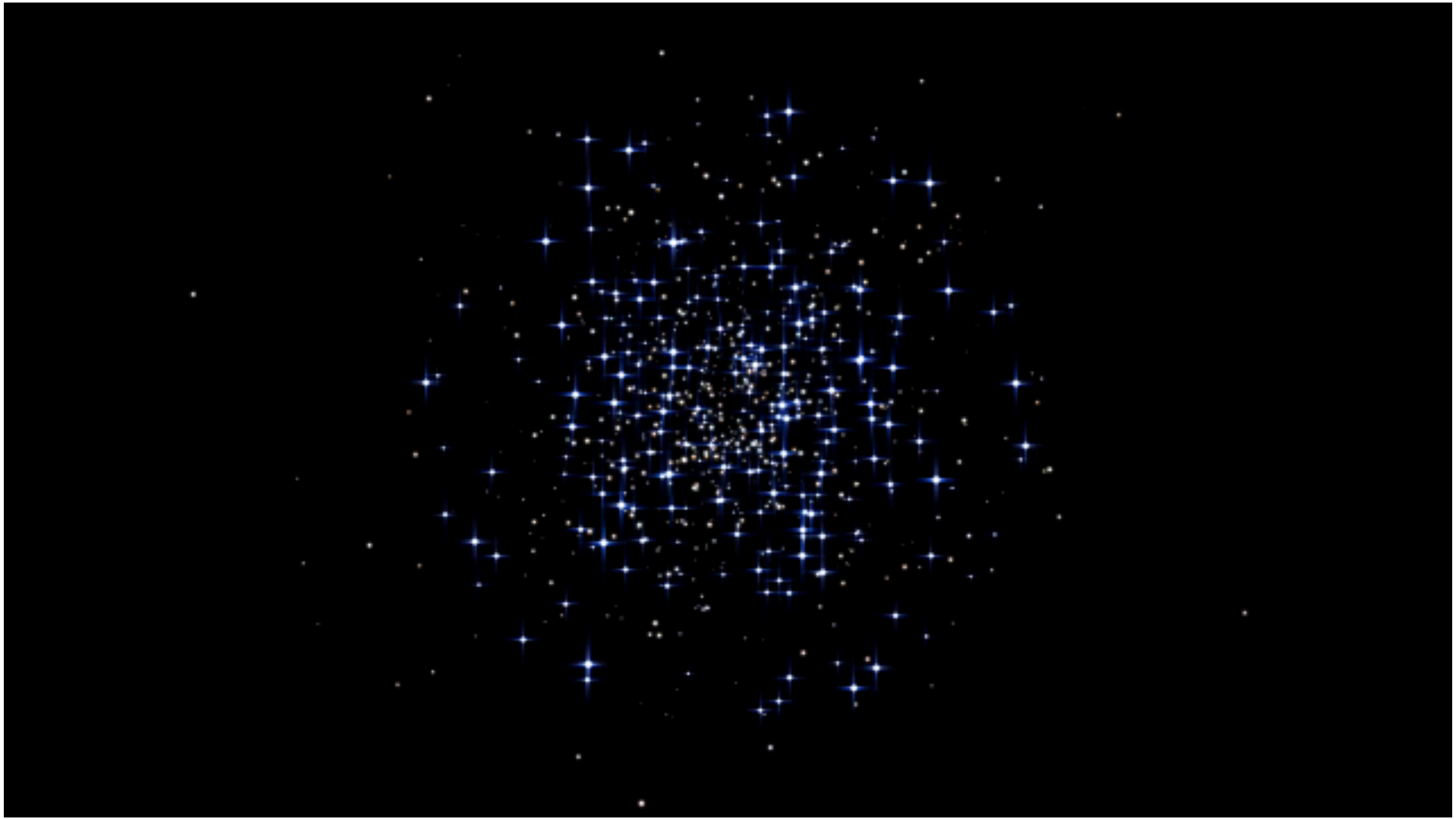
Cosmic-Lab

- 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?

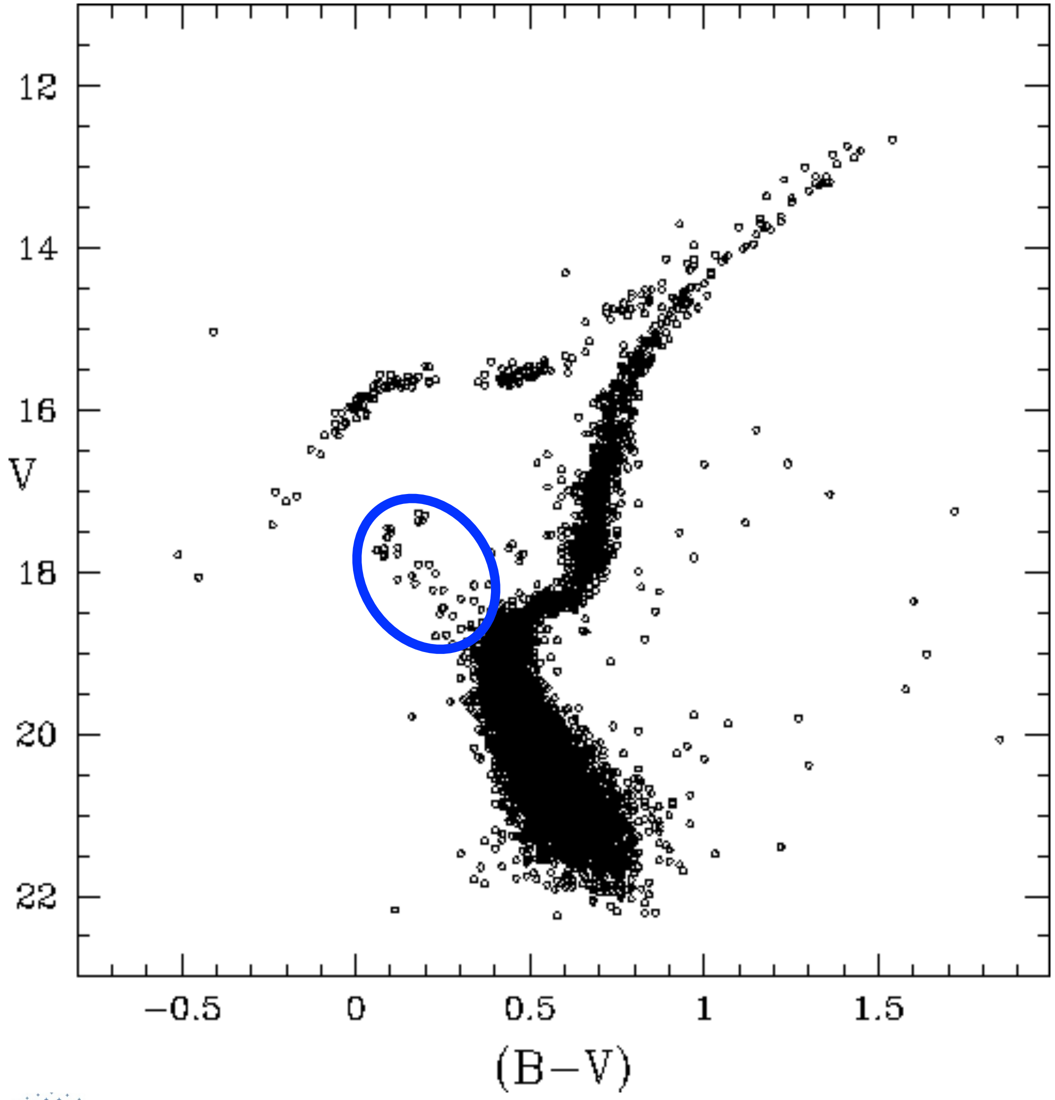


GC are the only stellar systems able to undergo nearly all the physical processes known in stellar dynamics over a time scale significantly shorter than the Hubble time.

This dynamical activity can generate **exotica**

Blue Straggler Stars (BSS)

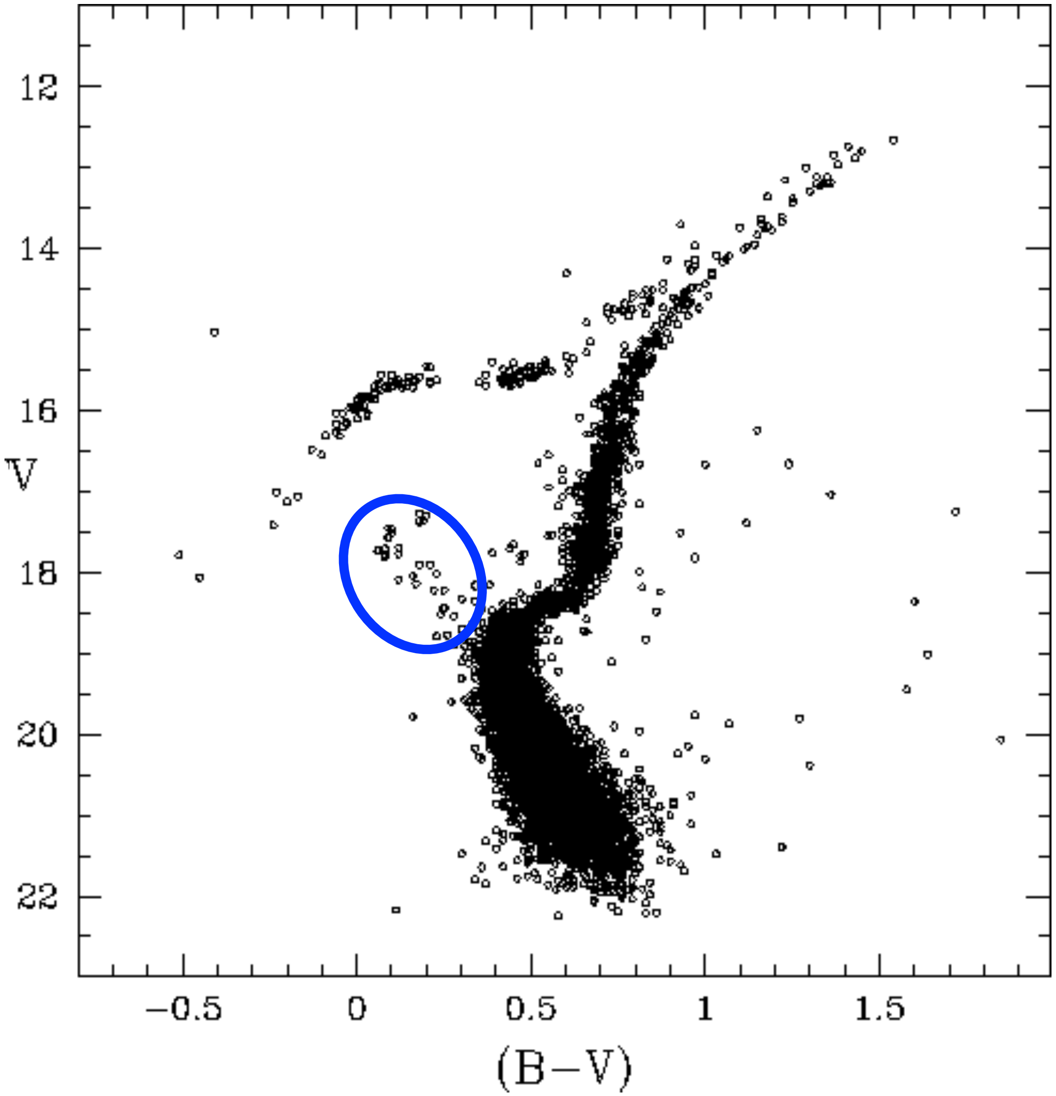
A PECULIAR stellar population



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)

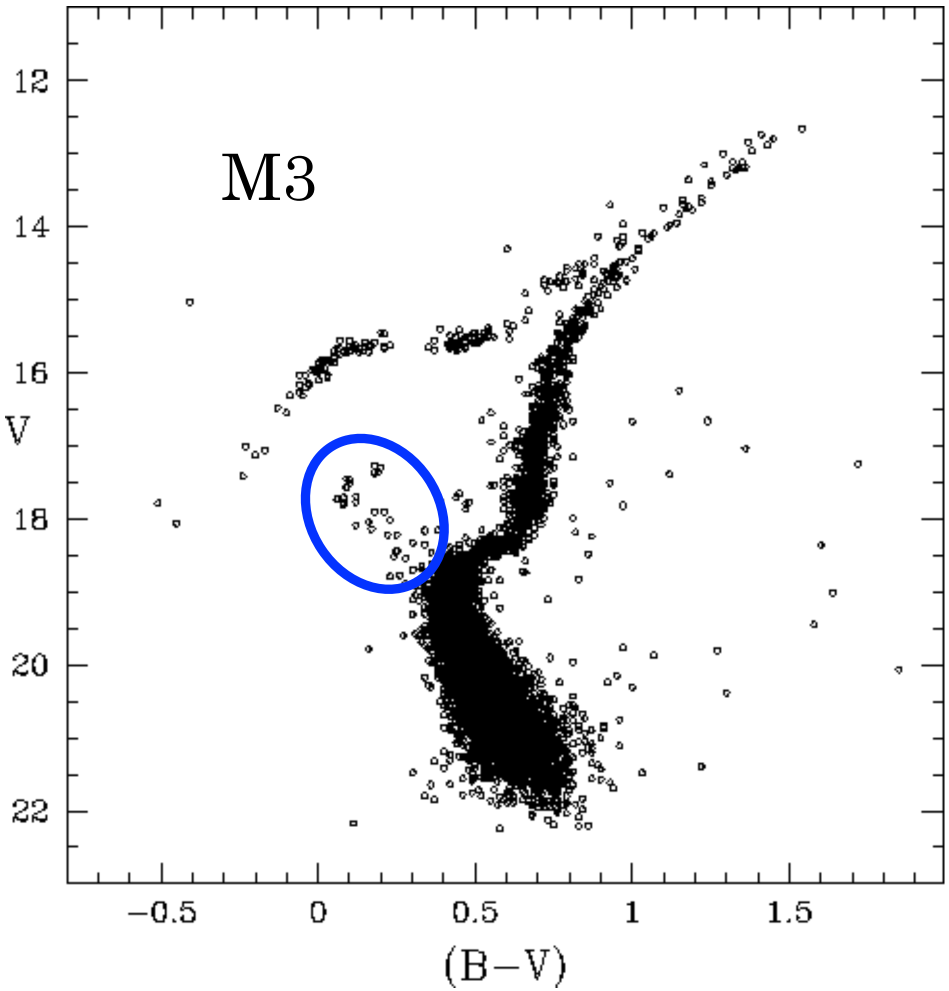


..while
old “normal” stars define
a sort of flock of tired stars
getting progressively
redder

BSS appear as a bunch
of “apparently” younger
blue stars

Blue Straggler Stars (BSS)

Blue Straggler Stars (BSS)

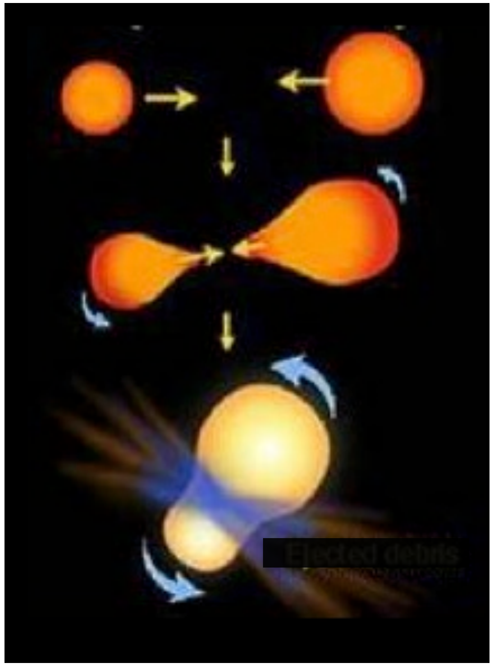


They LOOK younger but they are OLD stars rejuvenated by dynamical processes

Merger of two low-mass stars

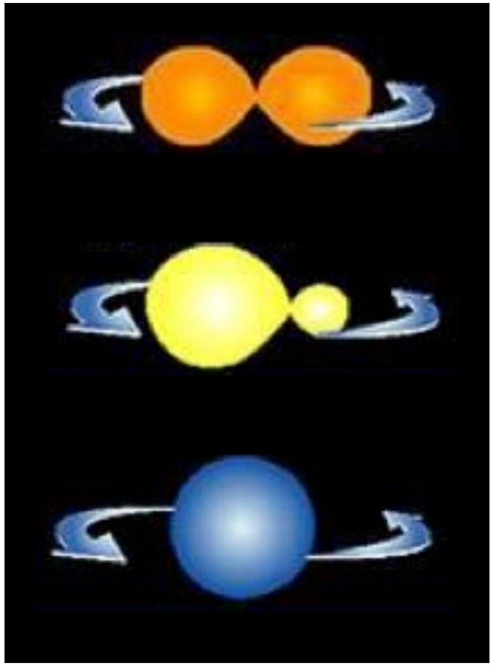
The formation mechanisms

COLLISIONS



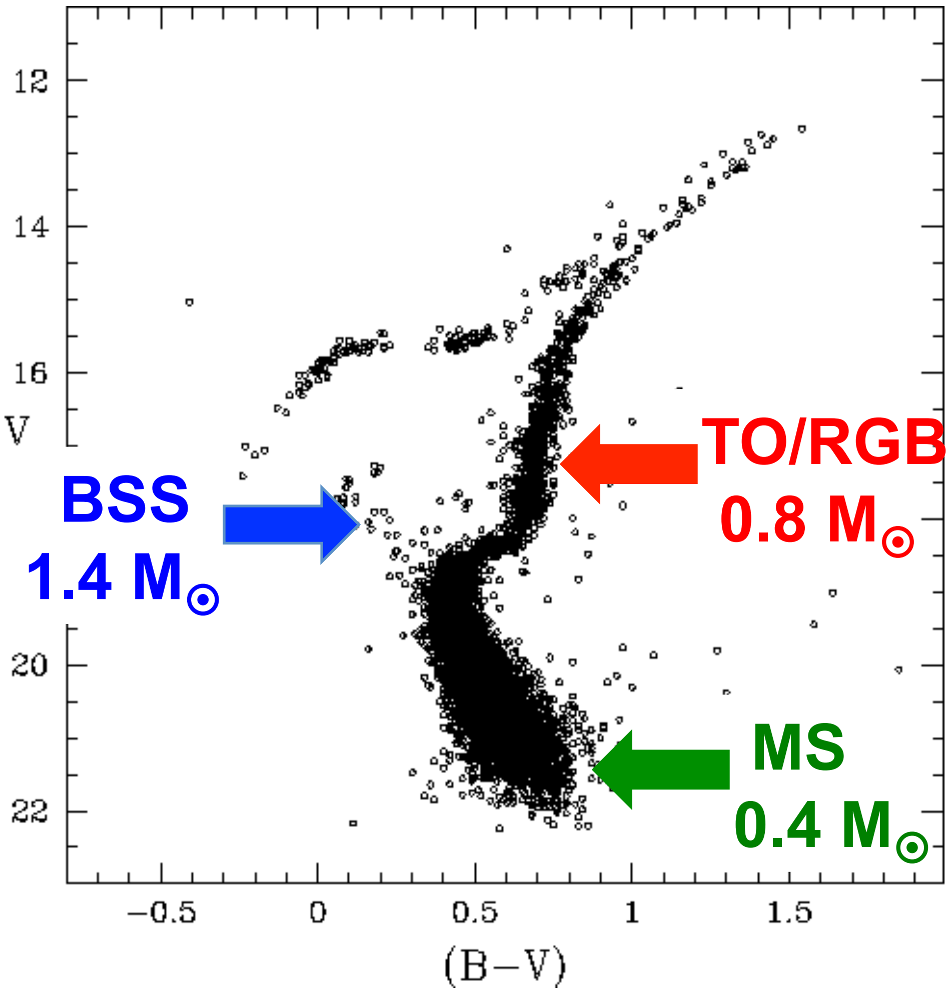
depend on **collision** rate
(Hills & Day 1976)

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}=1.2-1.4 $M_\odot$) orbiting in 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**

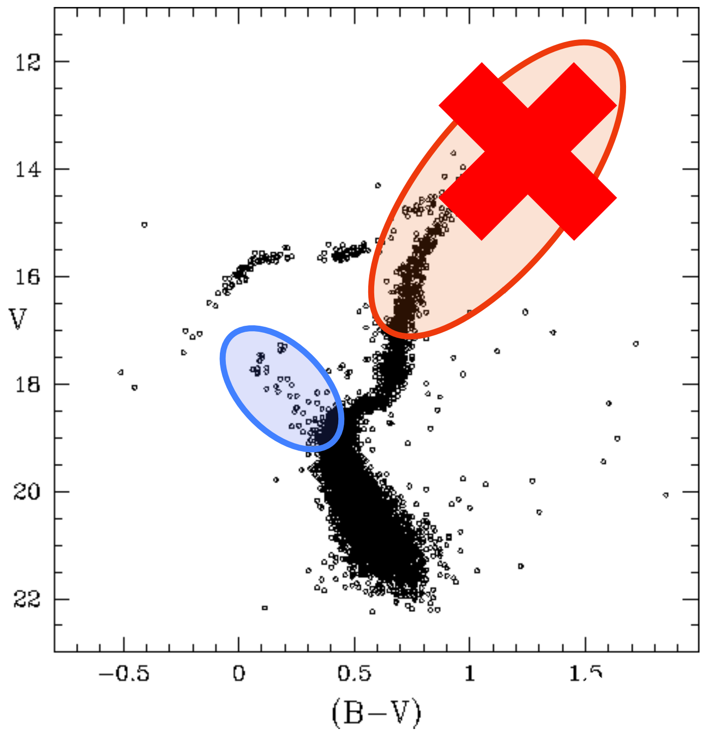
$$t_{df} \approx \frac{1}{M_{BSS}\,\rho(r)}$$

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

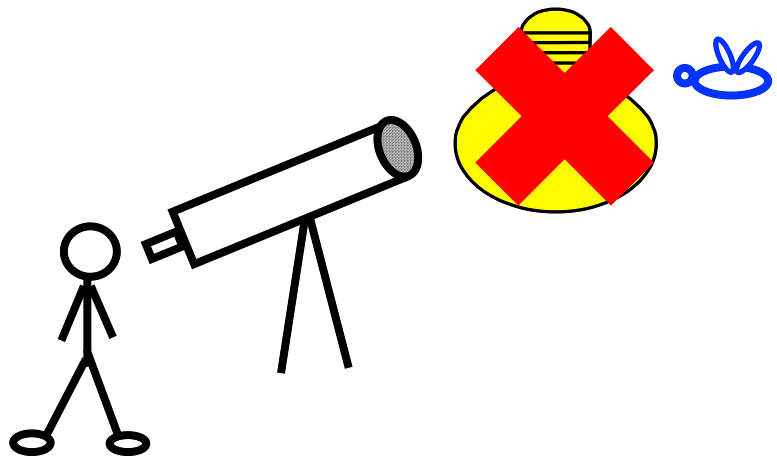
What we need to know is the radial distribution of these heavy objects within the entire cluster extension

Observations of Blue Stragglers in Globular Clusters: really NOT an easy task !!

The Optical emission in GCs is DOMINATED by Cool giants (RGB/AGB) are much brighter than BSS



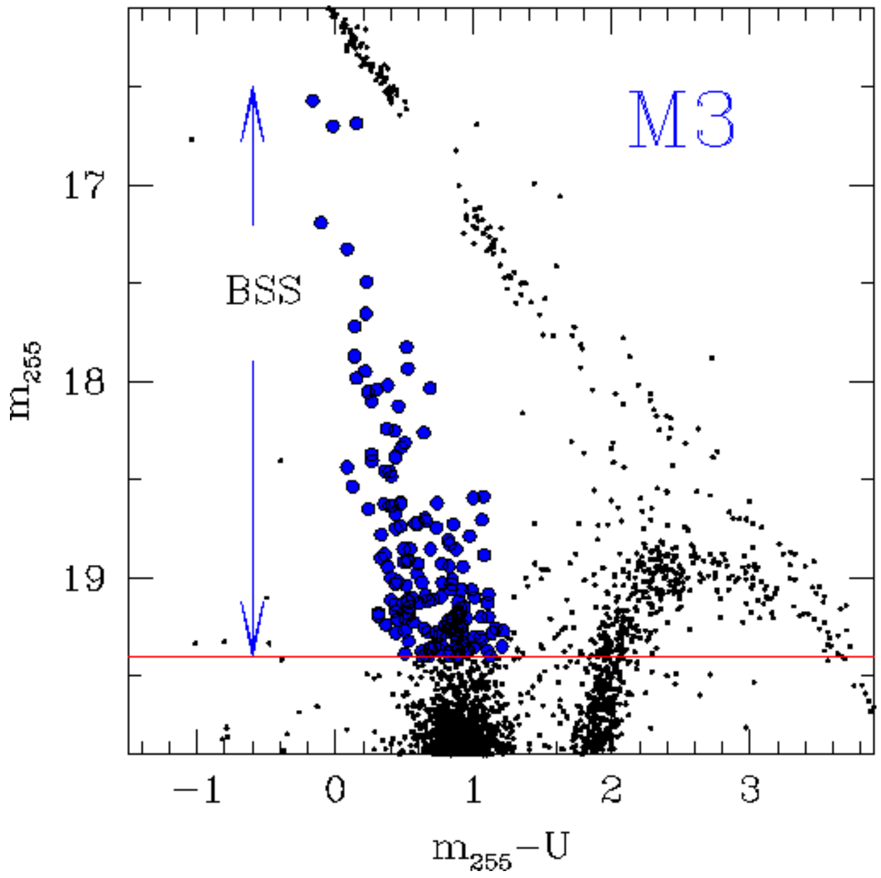
… like trying to distinguish a fire-fly having a HUGE light bulb just in front!



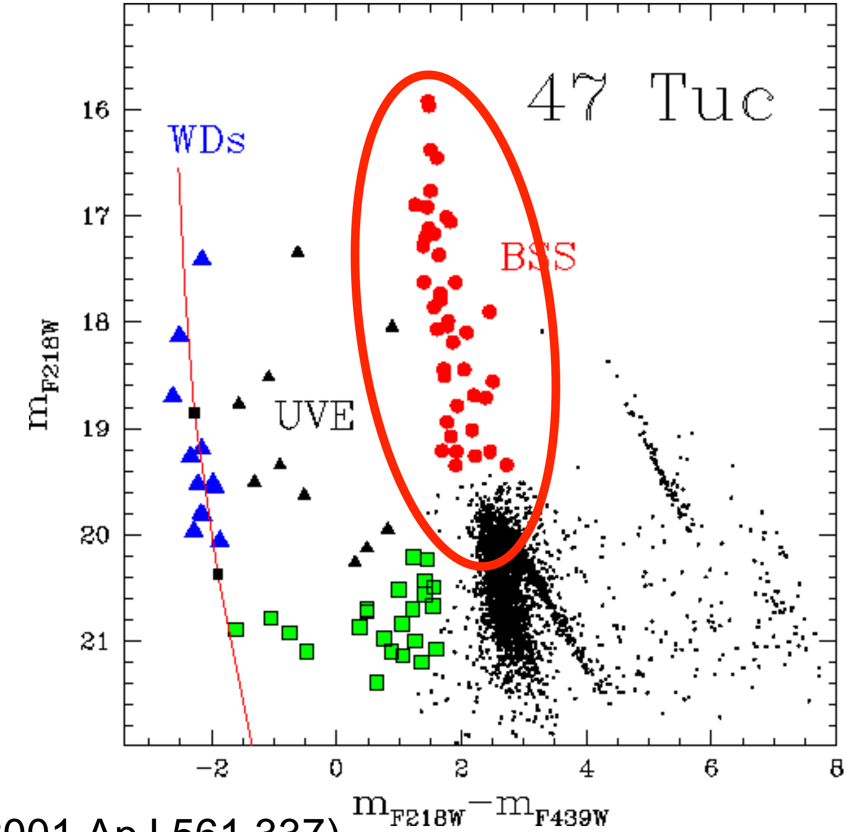
BSS in the UV:

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

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

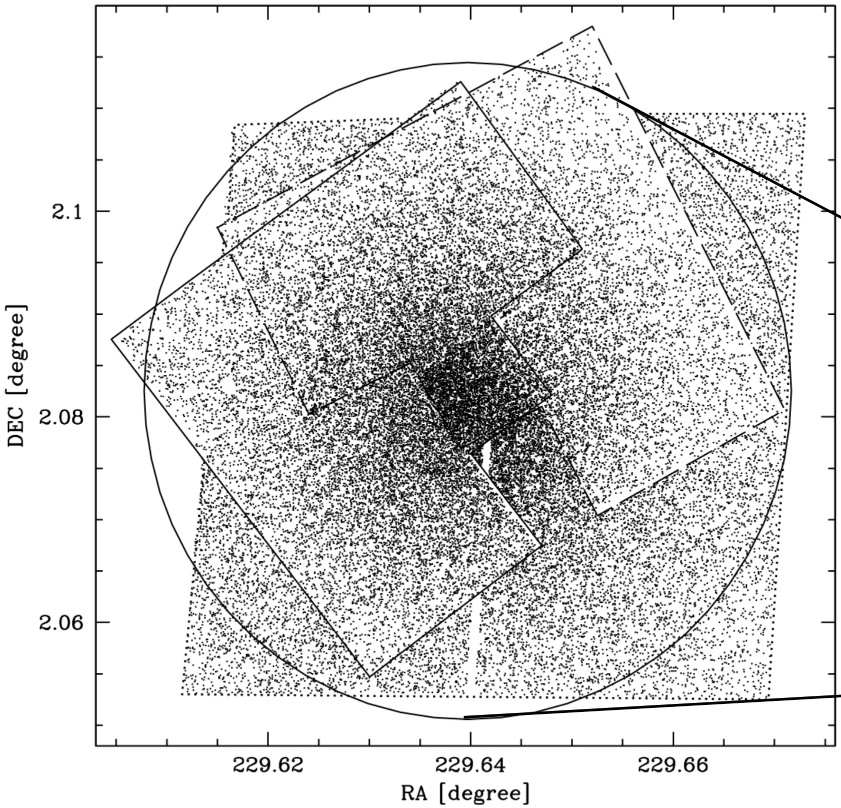


Ferraro et al (1997,A&A,324,915)

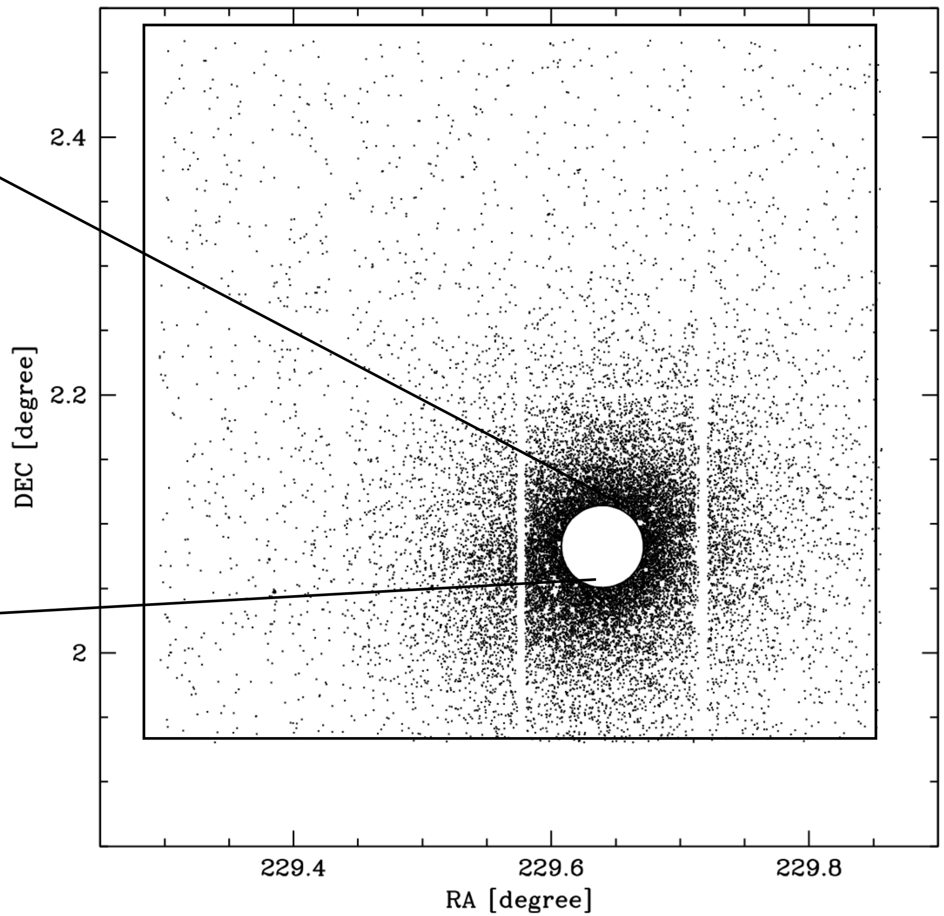


Ferraro et al (2001,ApJ,561,337)

High-res: HST/WFPC2+ACS

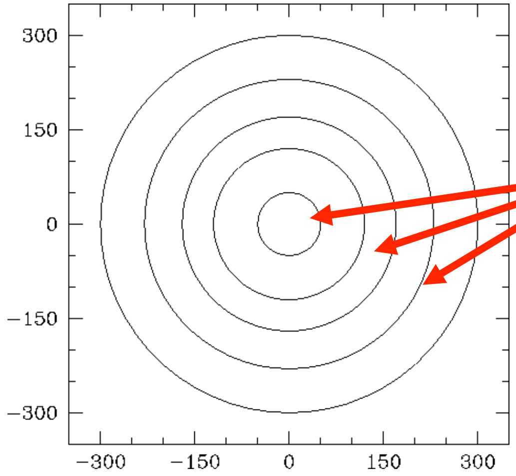


Wide-field ground-based imaging



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

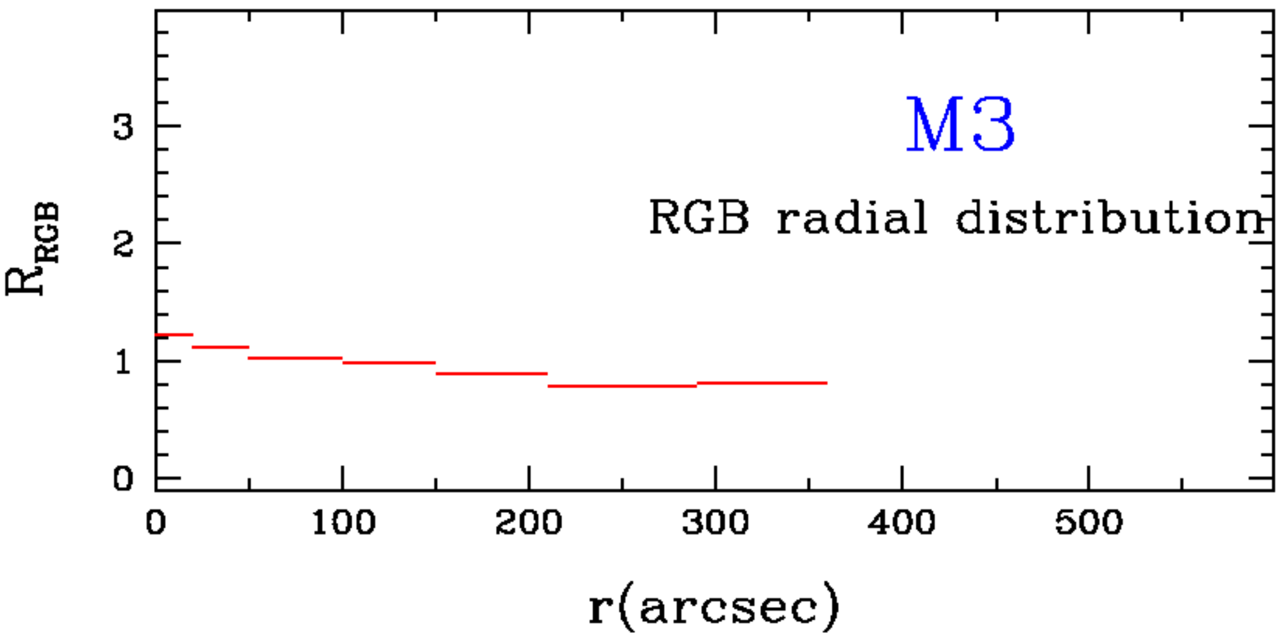
THE BSS RADIAL DISTRIBUTION



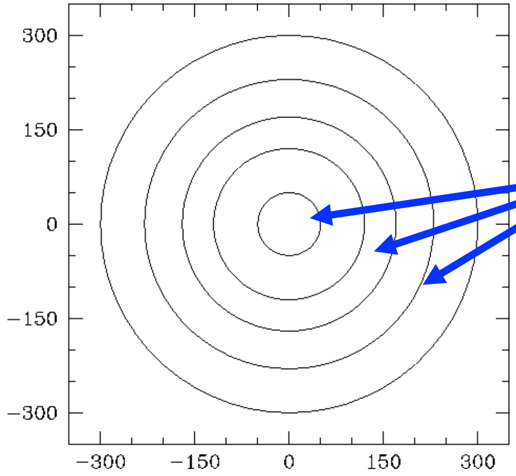
$$R_{RGB} = \frac{N_{RGB}/N_{RGB,TOT}}{L_{samp}/L_{TOT}}$$

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

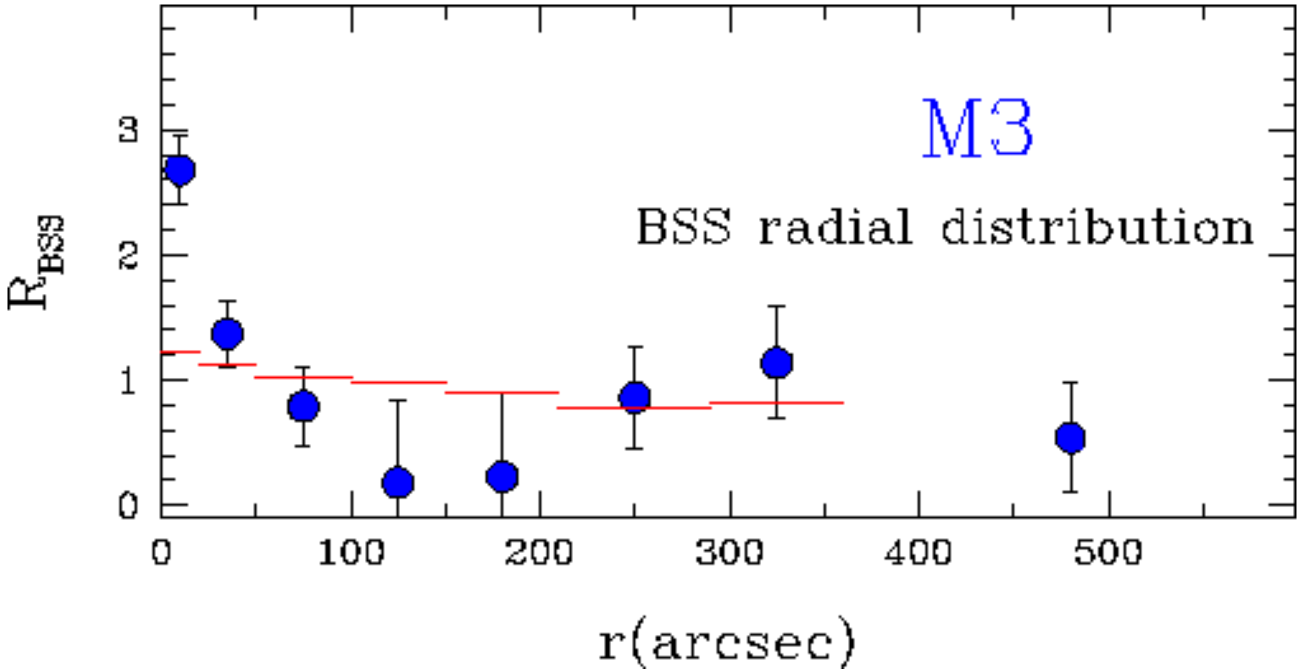
Note that ***a flat distribution*** in this plot means that ***"the number of stars in each annulus exactly scales with the cluster light sampled in each annulus"***



THE BSS RADIAL DISTRIBUTION

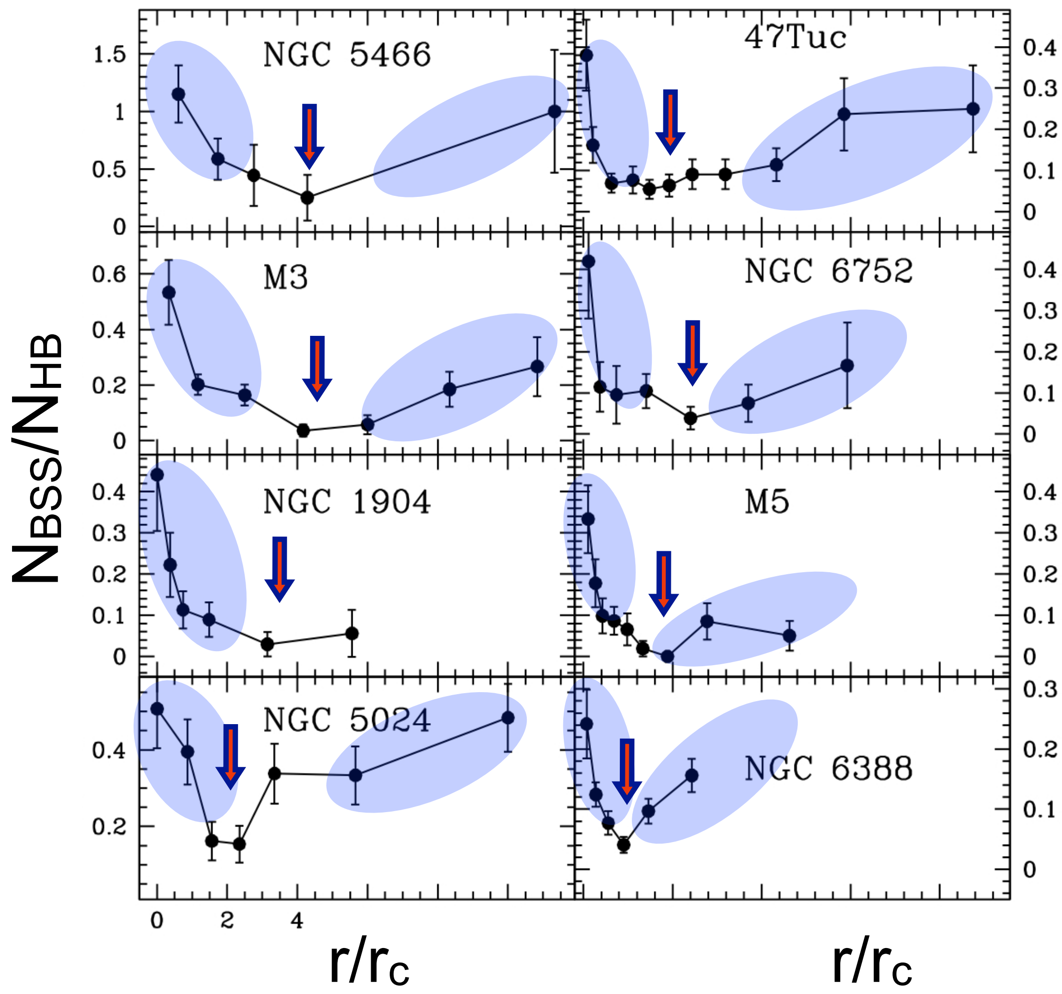


$$R_{BSS} = \frac{N_{BSS}/N_{BSS,TOT}}{L_{samp}/L_{TOT}}$$



BSS radial distribution

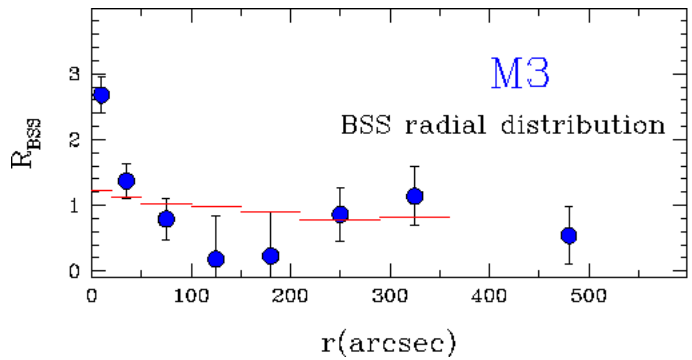
Over the last 15 years we studied the BSS radial distribution over the entire cluster extensions in 25 stellar systems. Finding a variety of cases



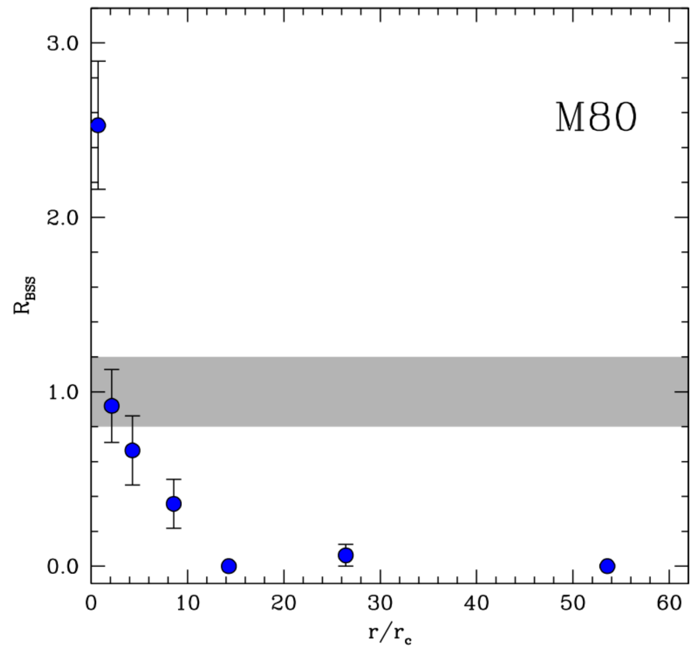
BSS radial distribution

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

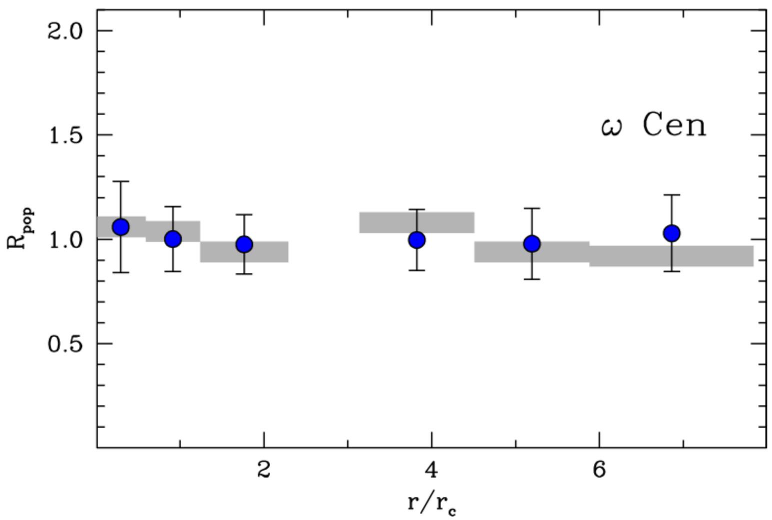
"bimodal"



"Unimodal" (single-peak)



"Flat"



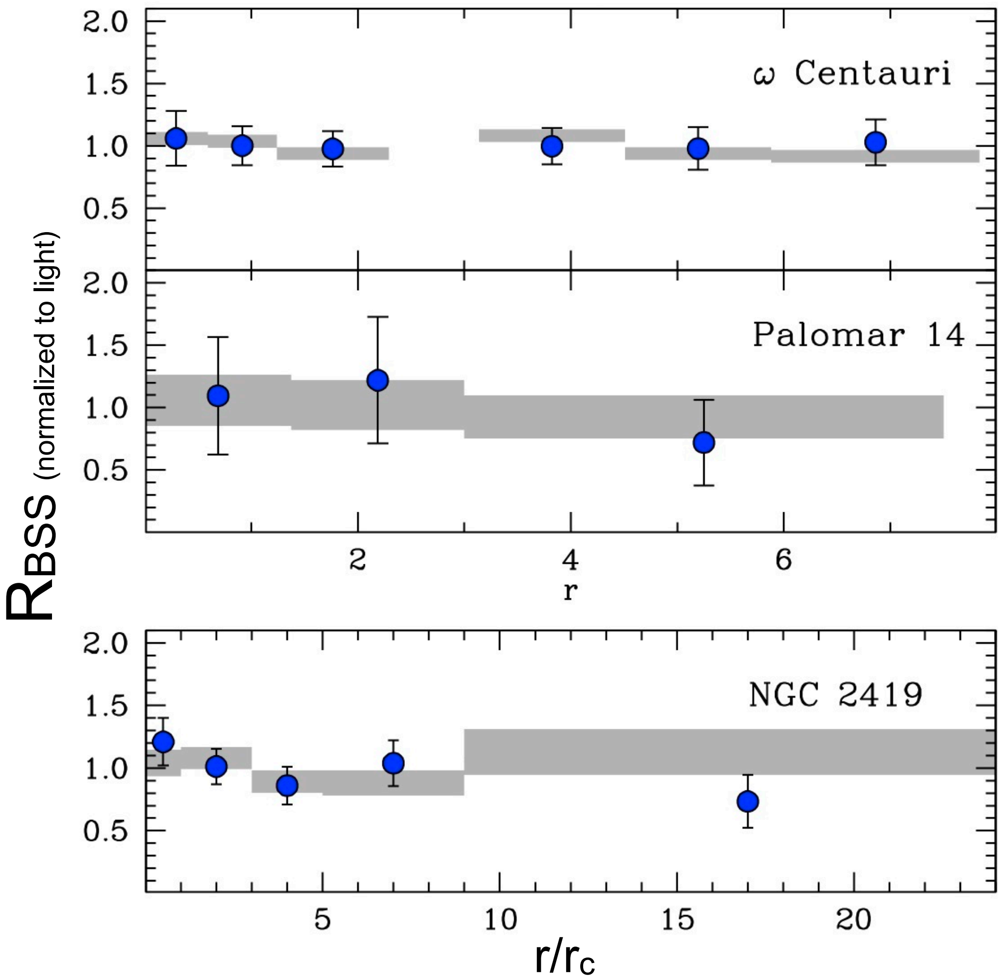
The BSS radial distribution is shaped by dynamical friction, which segregates BSS progressively in time

….. 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 fully agreement with that of "normal stars"

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

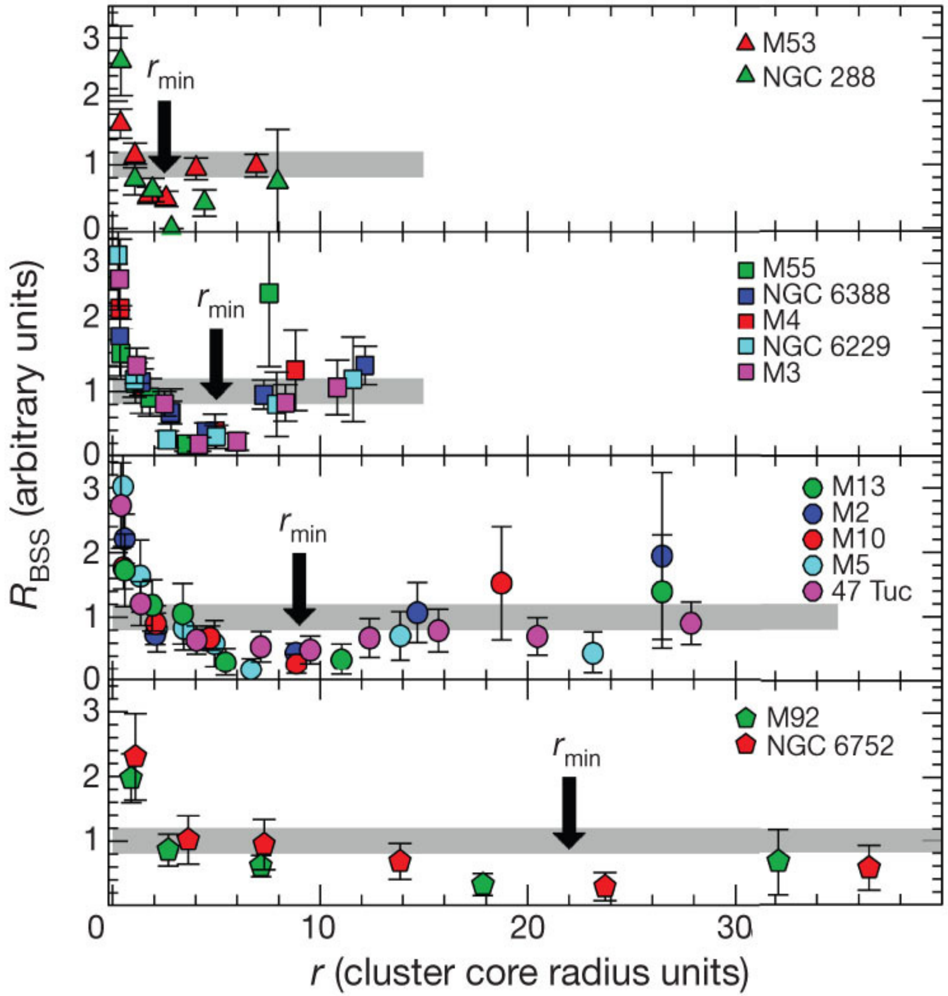
Note that this is the **most efficient way** to prove that these stellar systems are not relaxed yet

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

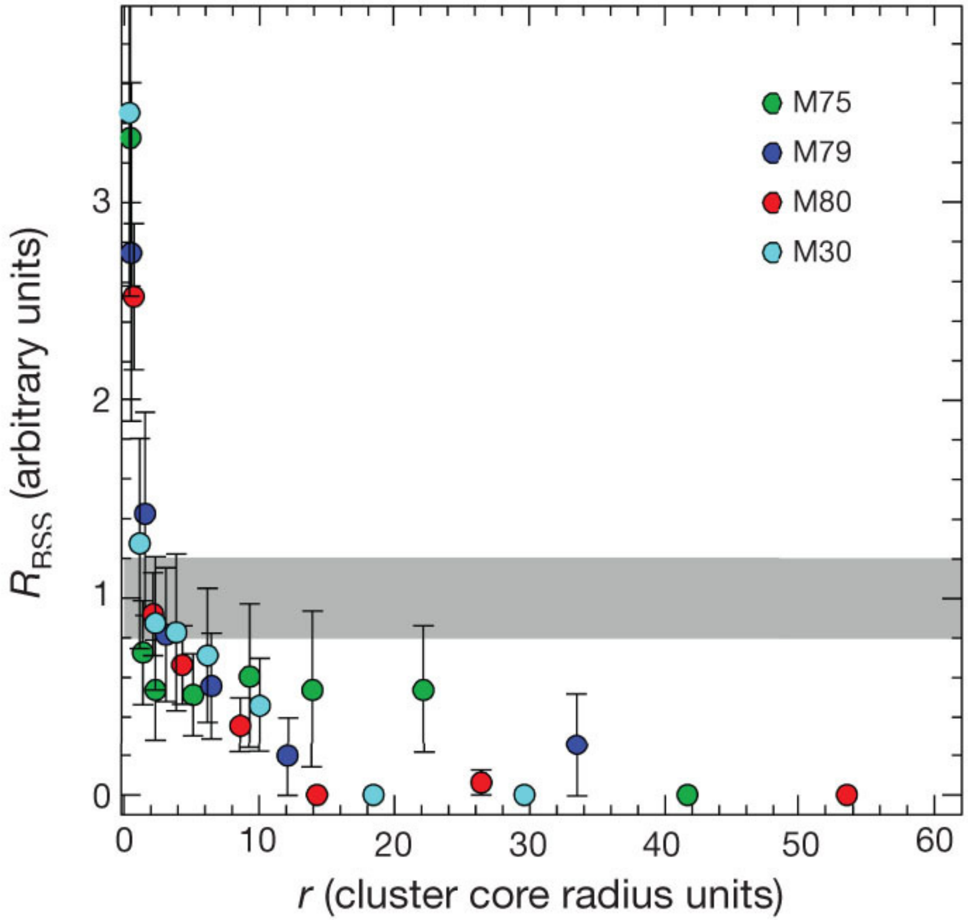
The action of **df** extends progressively at larger distances from the cluster center = the minimum is moving progressively outward

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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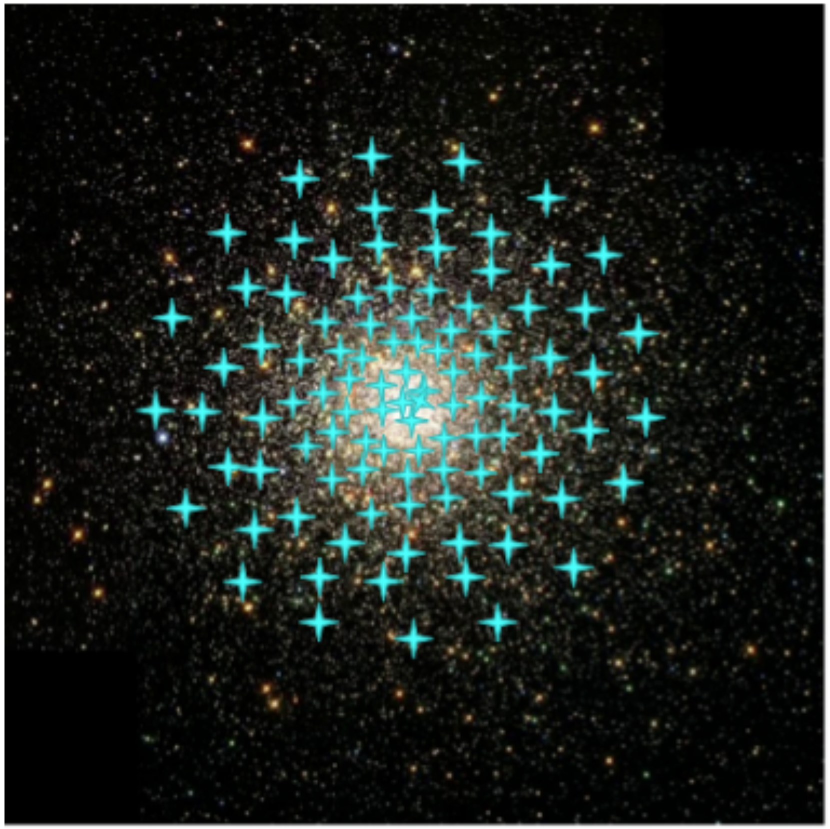
The dynamical clock

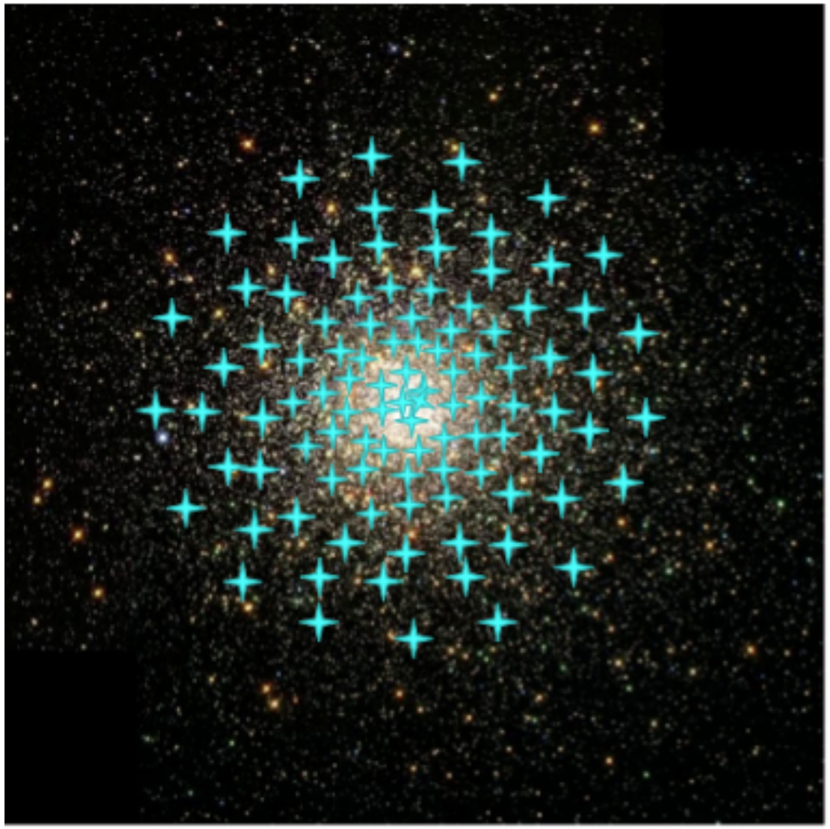
Ferraro et al (2012,Nature,492,393)



The cartoon illustrates the action of the **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

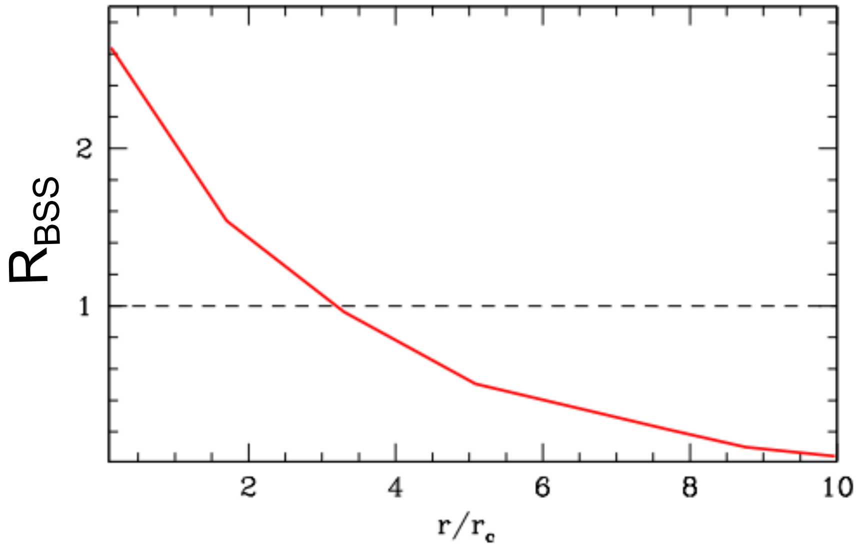
Ferraro et al (2012,Nature,492,393)



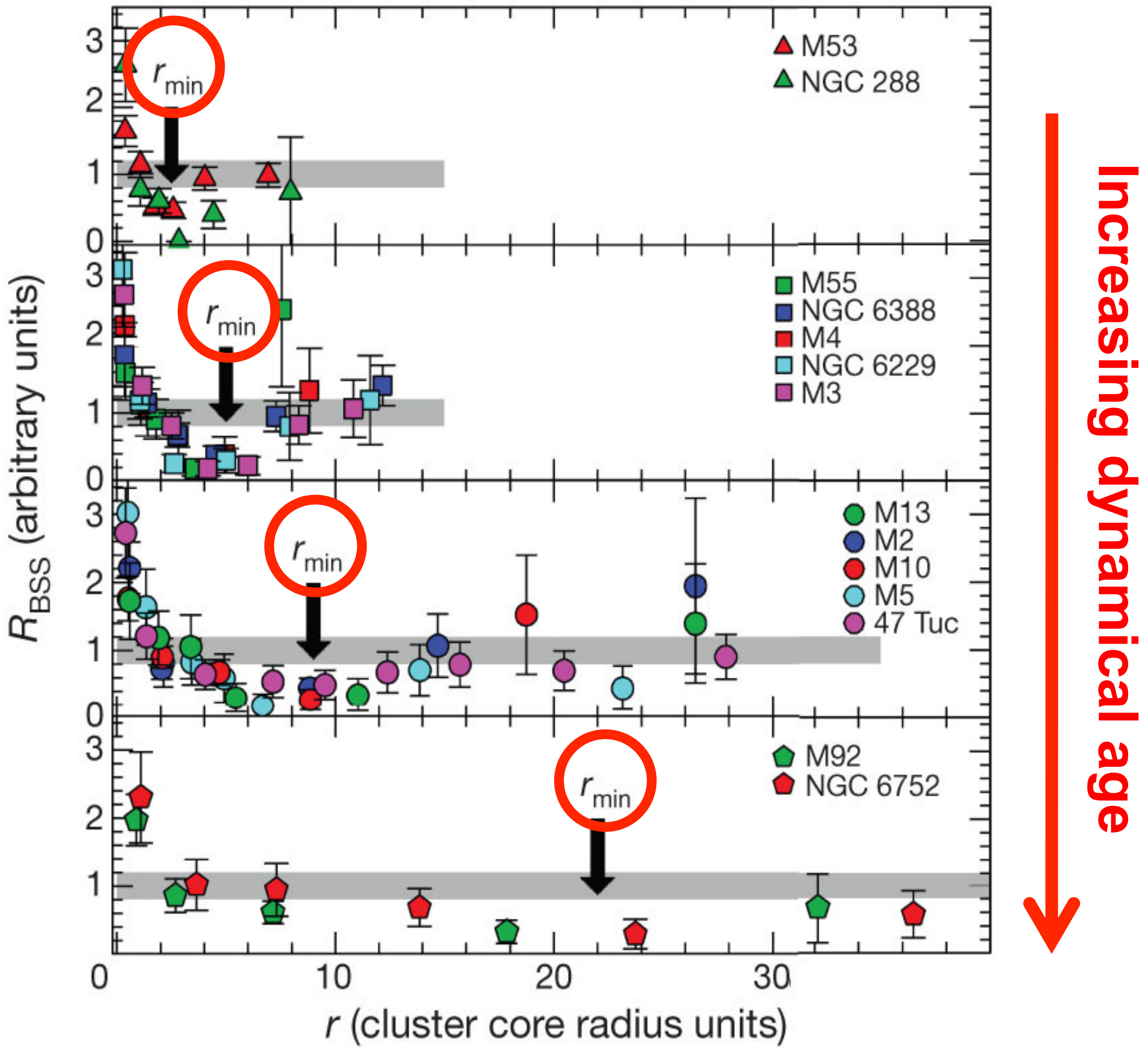
The cartoon illustrates the action of the **df** that progressively segregates the BSS toward the cluster center producing a **dip in the radial distribution** that propagates toward the external region as a function of the time.

The dynamical clock

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



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

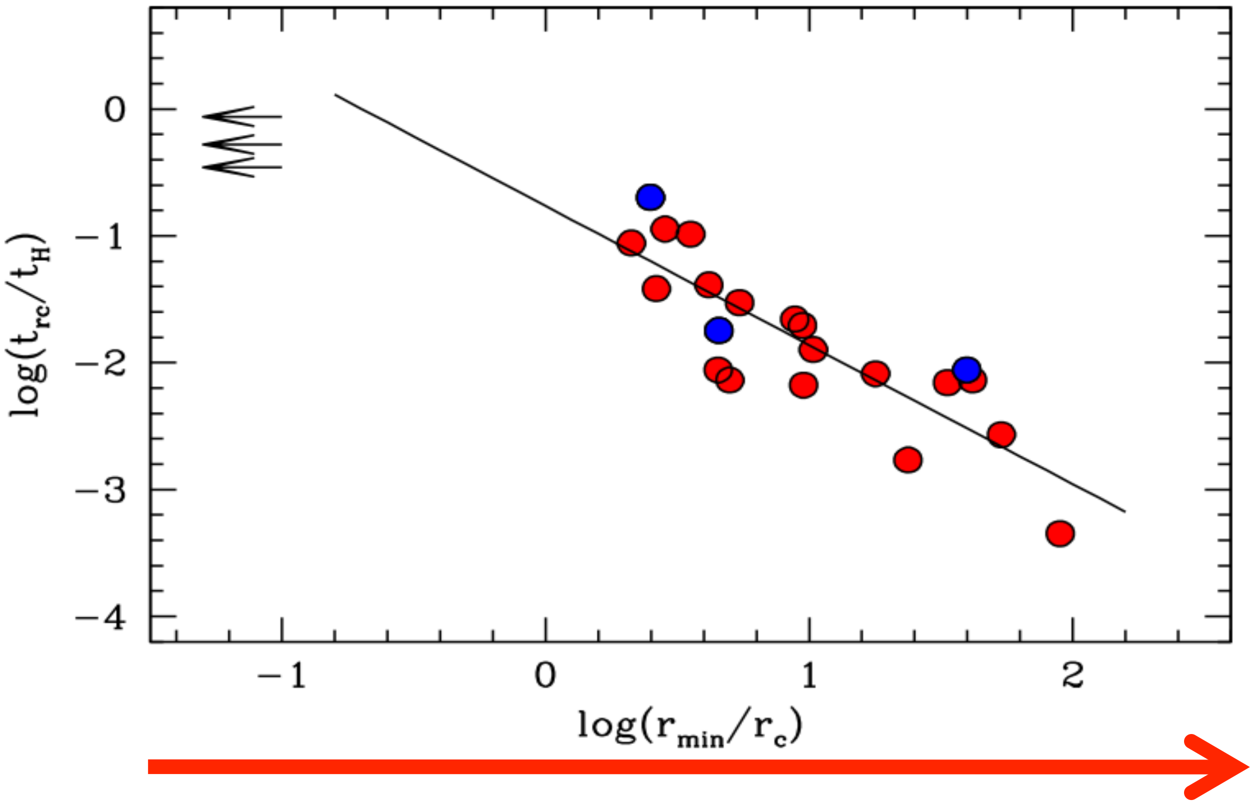


M53
NGC 288
M55
NGC 6388
M4
NGC 6229
M3
M13
M2
M10
M5
47 Tuc
M92
NGC 6752
r_{min}
R_{BSS} (arbitrary units)
r (cluster core radius units)
Increasing dynamical age

The dynamical clock

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

A fully empirical tools able to rank stellar systems in terms of their dynamical age. The position of the hand of the clock nicely agrees with theoretical estimates of the central relaxation time (t_{rc})



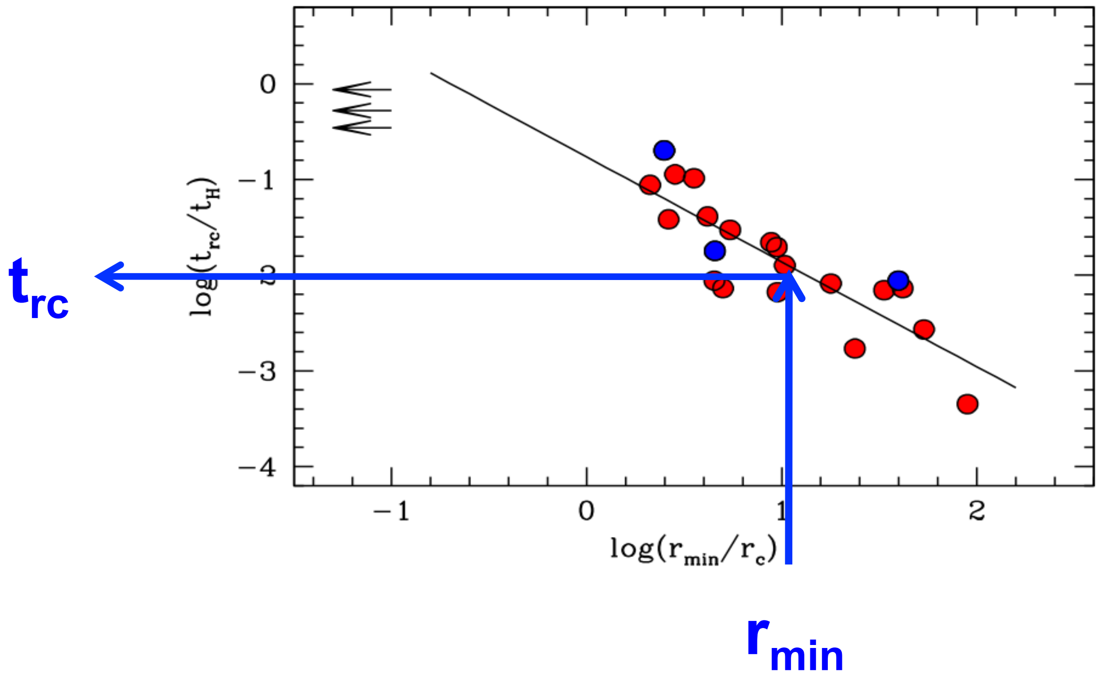
Increasing dynamical age

Cosmic-Lab

The dynamical clock

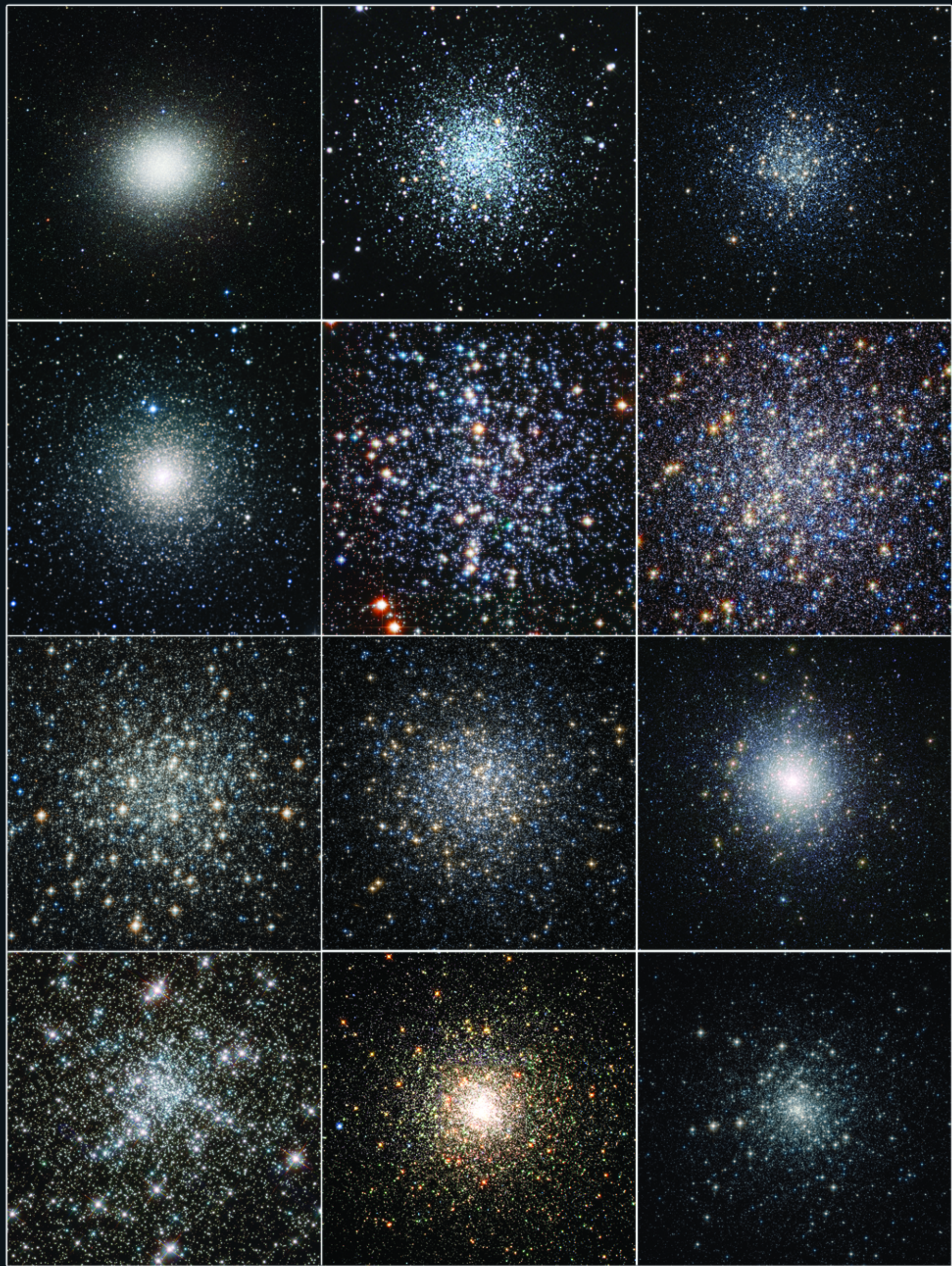
Ferraro et al (2012,Nature,492,393)

$$\mathrm{Log}(t_{rc}/t_H) = -1.11\ \log(r_{min}/r_c) - 0.76$$



This tool is much more powerful than any previous theoretical estimator of the dynamical time-scale (e.g. the relaxation time-scale at the cluster center) since it simultaneously probe all distances from the cluster center

THE DYNAMICAL CLOCK

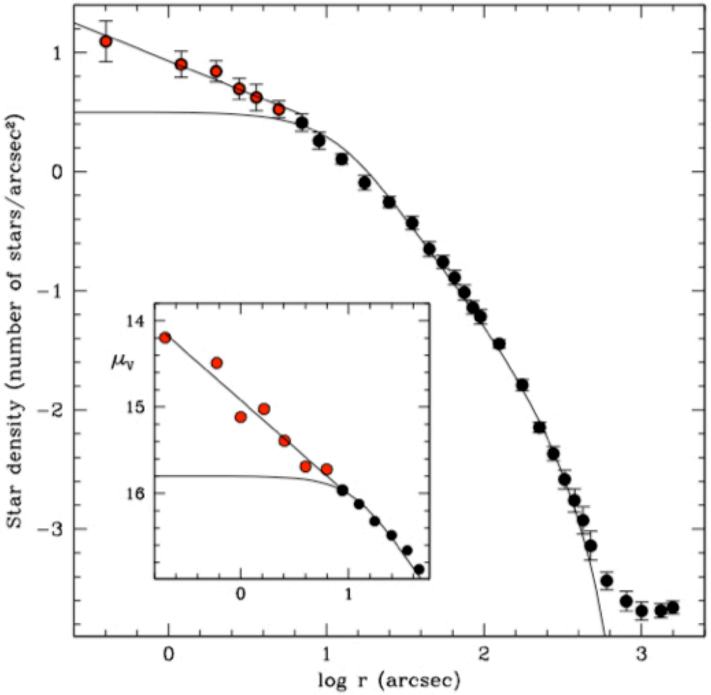


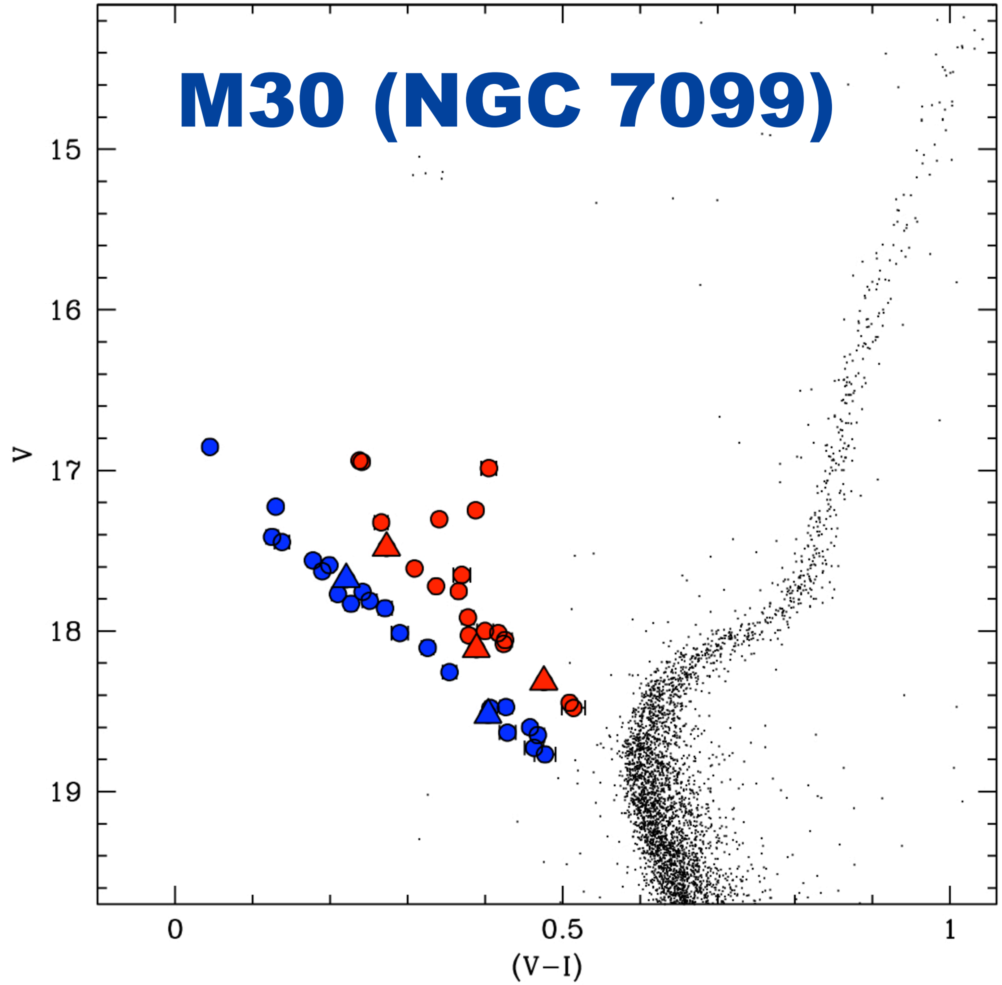
Mosaic of 12 images of Milky Way globular clusters ranked in order of increasing dynamical age, as measured by the "dynamical clock of stellar systems".
From top-left, to bottom-right: omegaCentauri, NGC 288, M55, NGC 6388, M4, M13, M10, M5, 47 Tucanae, NGC 6752, M80, and M30.

Globular clusters are stellar aggregates counting up to a few million stars. Most of them formed at the same cosmic epoch (12-13 billion years ago, slightly after the Big Bang)

Indeed we can do even more…..

BSS sequences might provide crucial information about one of the most spectacular dynamical event in the cluster lifetime: **the collapse of the core**





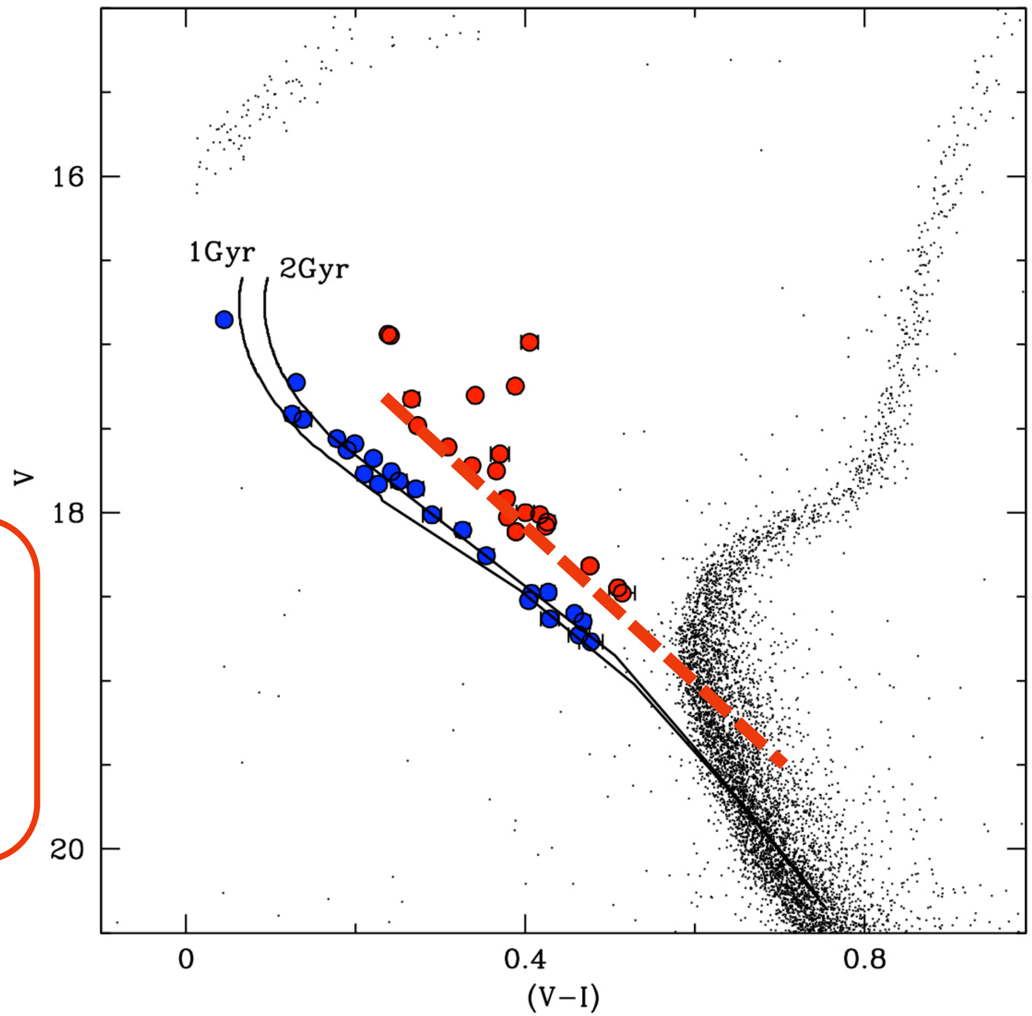
2 distinct sequences of BSS !!

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

BSS double sequences probe & date the cluster core-collapse

- **blue-BSS sequence well reproduced by collisional isochrones of 1-2 Gyr** (Sills et al 2009)

Red-BSS sequence is consistent with the low-luminosity boundary defined by the evolution of PB during MT stages (Tian et al 2006)



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Why did we not observe the double-BSS sequence in all the clusters ???

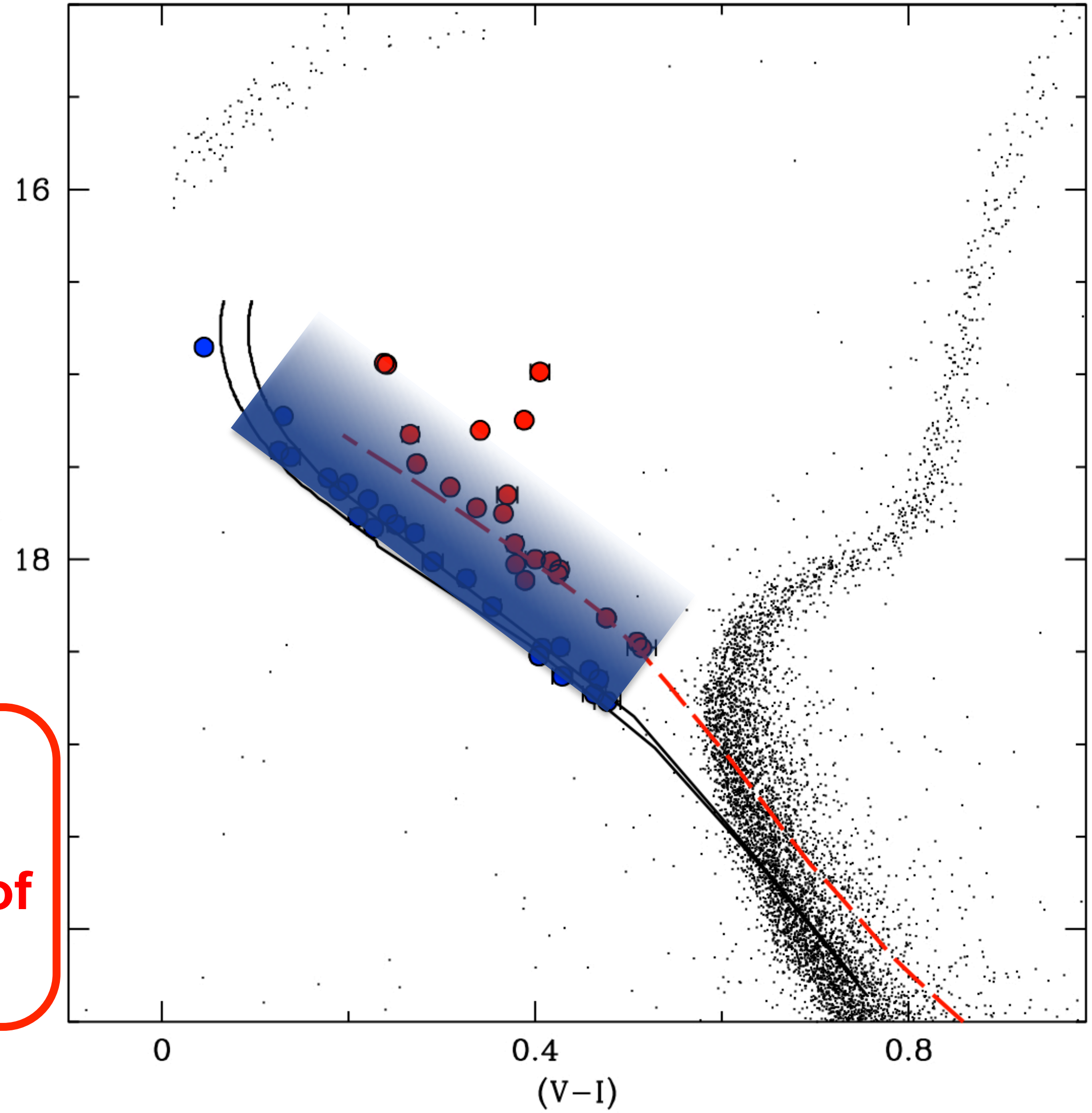
• **blue-BSS → collisional** **red-BSS → MT binaries**

double BSS seq. is NOT a permanent feature

The evolution of the **BLUE** Seq. will fill the gap in a few Gyr

⇓

The blue-BSS population must have formed recently ~1 Gyr ago



cluster core-collapse occurred ~1 Gyr ago and boosted the formation of (at least) the COL-BSS

IS THE DOUBLE BSS SEQUENCE PHENOMENON CONNECTED WITH THE PCC STATUS ?

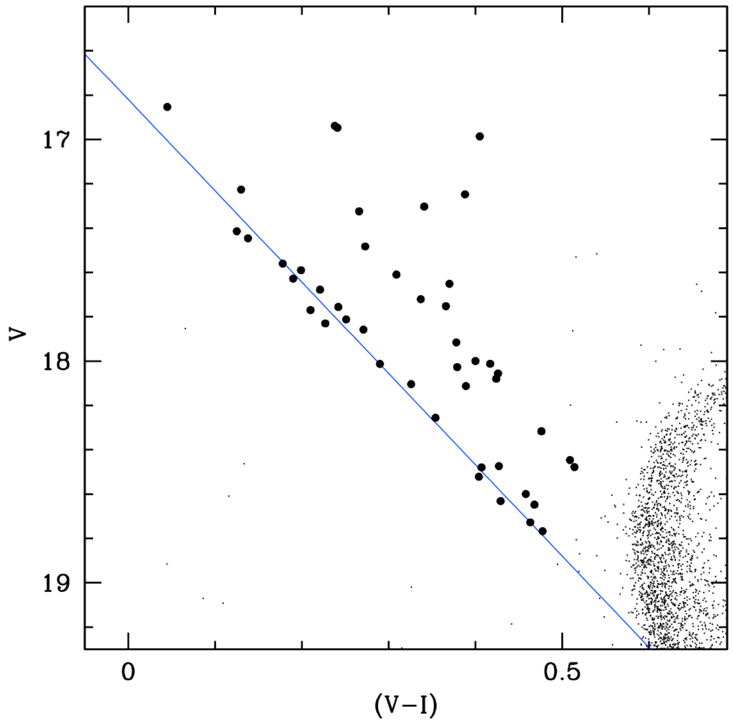
Is there any other PCC with a double BSS sequence?

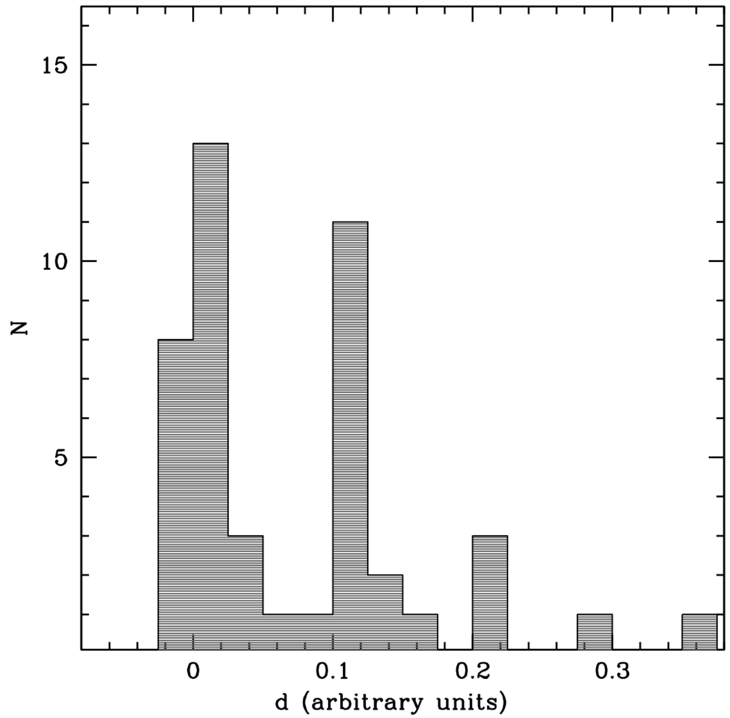
Classical PCC:
M15
NGC6397

Suspected PCC:
NGC362

BSS double sequence: The case of NGC6397

M30 (Ferraro et al. 2009)

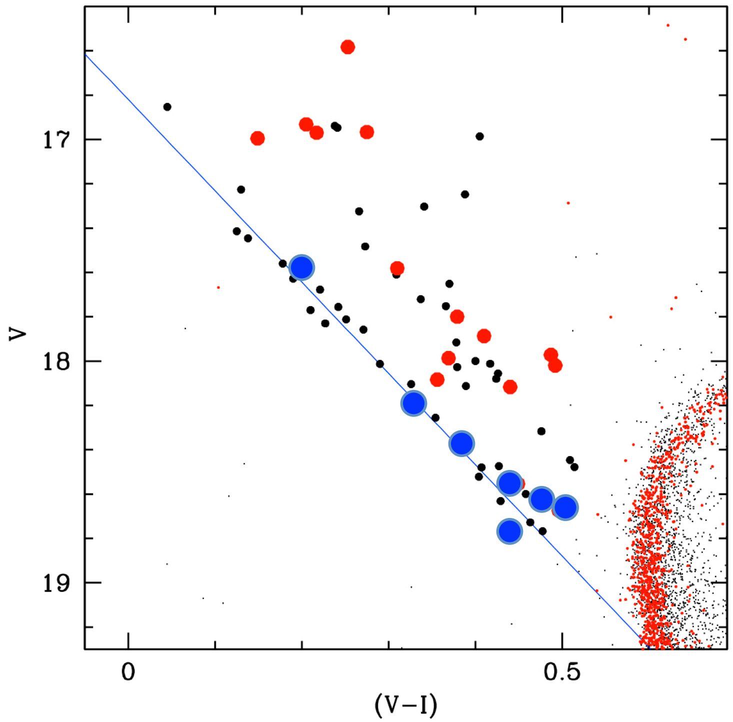


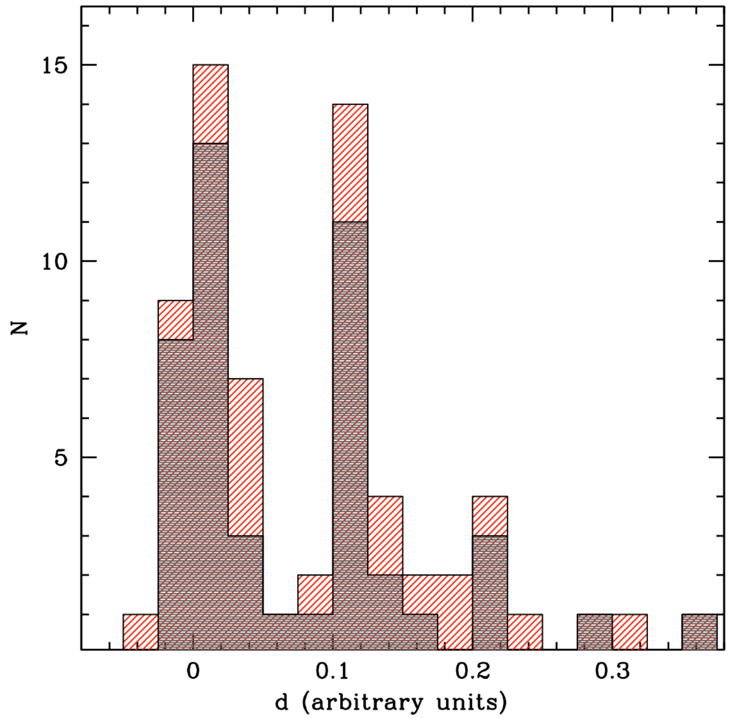


BSS double sequence: The case of NGC6397

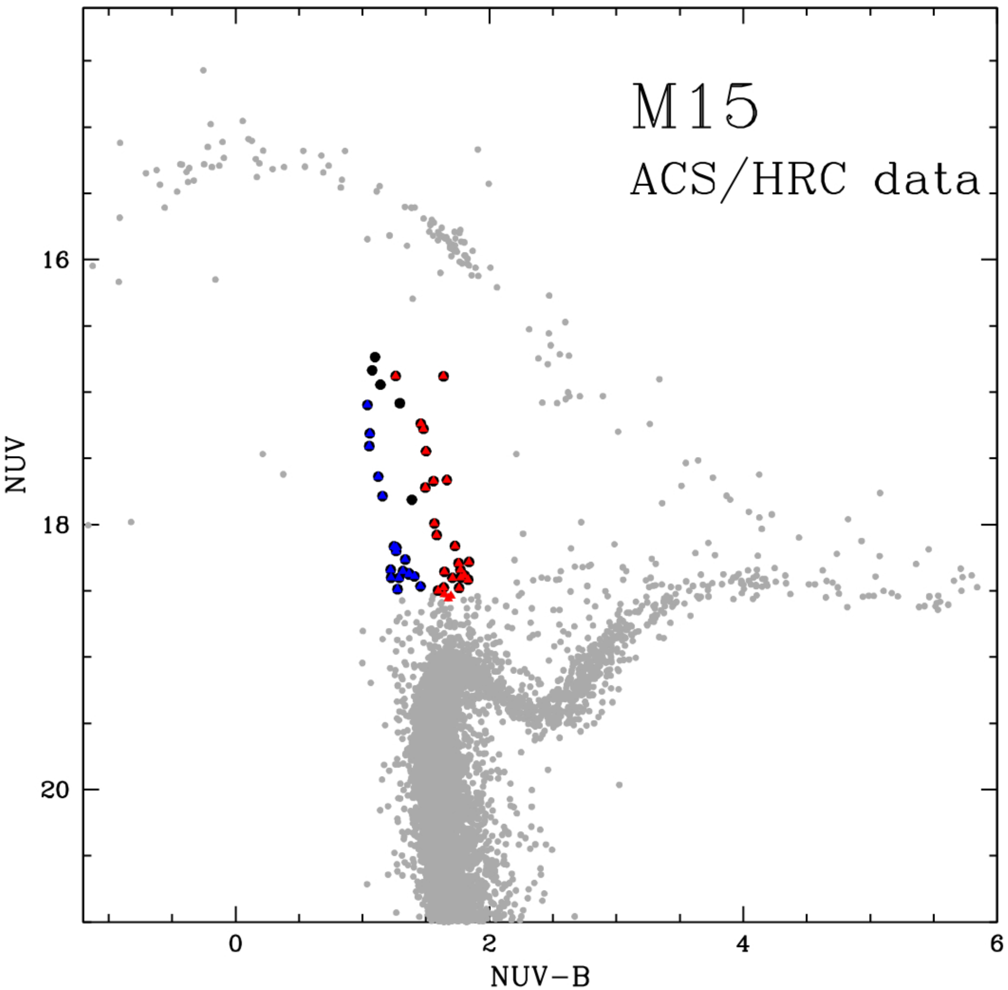
In the case of NGC6397 the **blue-BSS** sequence appear much less populated possibly suggesting that the core collapse in this cluster occurred much **earlier** than M30

NGC 6397 (Contreras et al. 2014, in preparation)



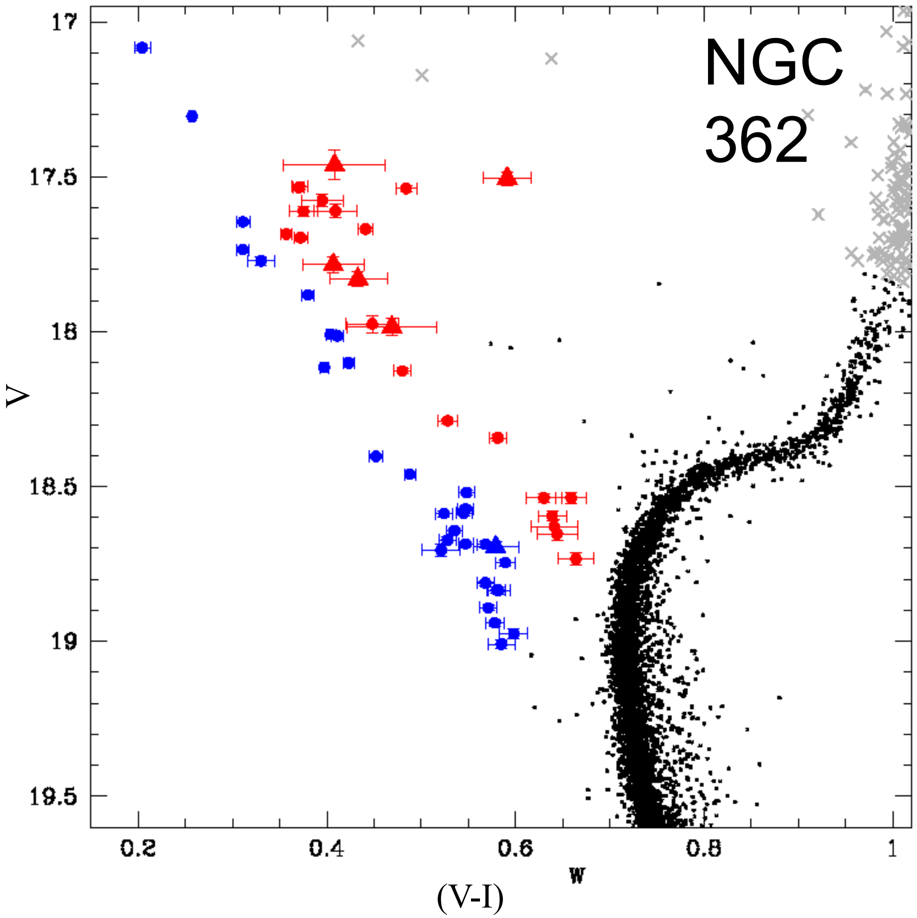


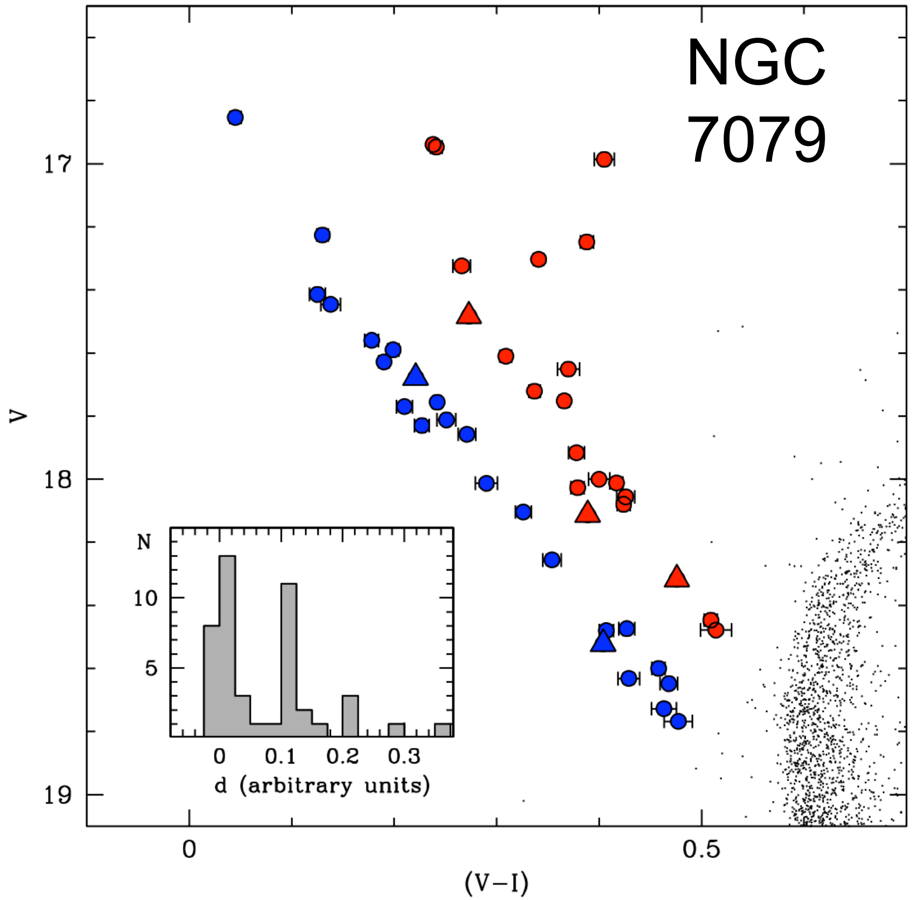
BSS double sequence: The case of M15



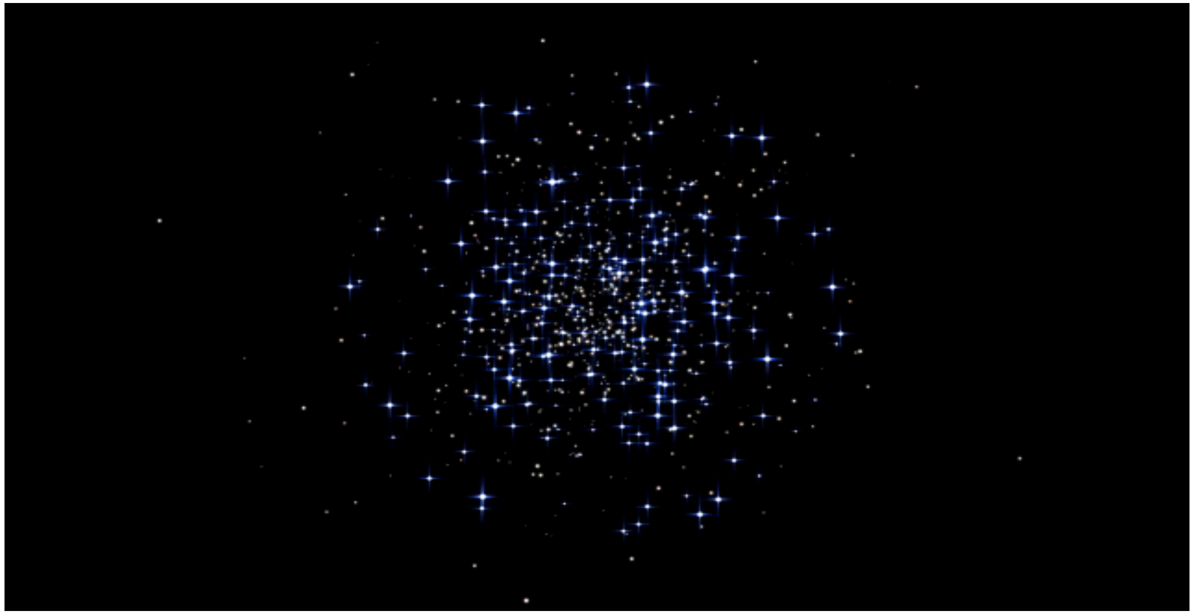
M15

BSS double sequence: The case of NGC362





Dalessandro et al. 2013



BSS are powerful probe of the parent cluster dynamics

Their properties (in terms of radial distribution, photometry, etc) seem to keep memory of the past history of the parent clusters offering us the possibility of dating their dynamical age and past crucial dynamical event (as the CC)…

…we have just started to learn how to read and interpret them….

The project web-page: http://www.cosmic-lab.eu/

We have created a web-page, where the entire scientific activity of the project (in terms of scientific results, products and tools, amount of awarded telescope time, press releases, freely downloadable images and videos and job opportunities) is constantly updated and can be monitored

Thank you for your attention !!!

Cosmic-Lab

You can download this presentation from our web-site: **www.cosmic-lab.eu**

The End