SAIt - Società Astronomica Italiana - INAF - Istituto Nazionale di Astrofisica

LVIII Congresso SAIt - MILANO - 13-16 maggio 2014 - Palazzo Cusani via Brera 15

"Strutture cosmiche: dal Sistema Solare ai confini dell'Universo"

An empirical clock to measure the dynamical age of stellar systems

FRANCESCO R. FERRARO

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Milano, May 14, 2014

THE PROJECT

- 5-year project funded by the European Research Council (ERC) with a grant of 1.9 MEuro

- *Advanced Research Grant* (2010 call)
  270 projects funded out of 2000 evaluated (13.8%),
  21 Italian project approved (7%)
  9 in Sciences of the Universe (3%)
  the only Italian project approved in Sciences of the Universe

- PI: Francesco R. Ferraro (Dip. of Physics & Astronomy – Bologna)

Cosmic-Lab

ERC Call	Applications received	Of which		
		Evaluated*	Funded	Success rates (%)**
Advanced Grant 2008	2,167	2,034	282	13.9
Advanced Grant 2009	1,584	1,526	245	16.1
Advanced Grant 2010	2,009	1,967	271	13.8
Advanced Grant 2011	2,284	2,245	301	13.4
Advanced Grant 2012	2,304	2,269	319	14.1
Advanced Grant 2013	2,408	2,363	284	12.0
Advanced Grant total	12,756	12,404	1,702	13.9***

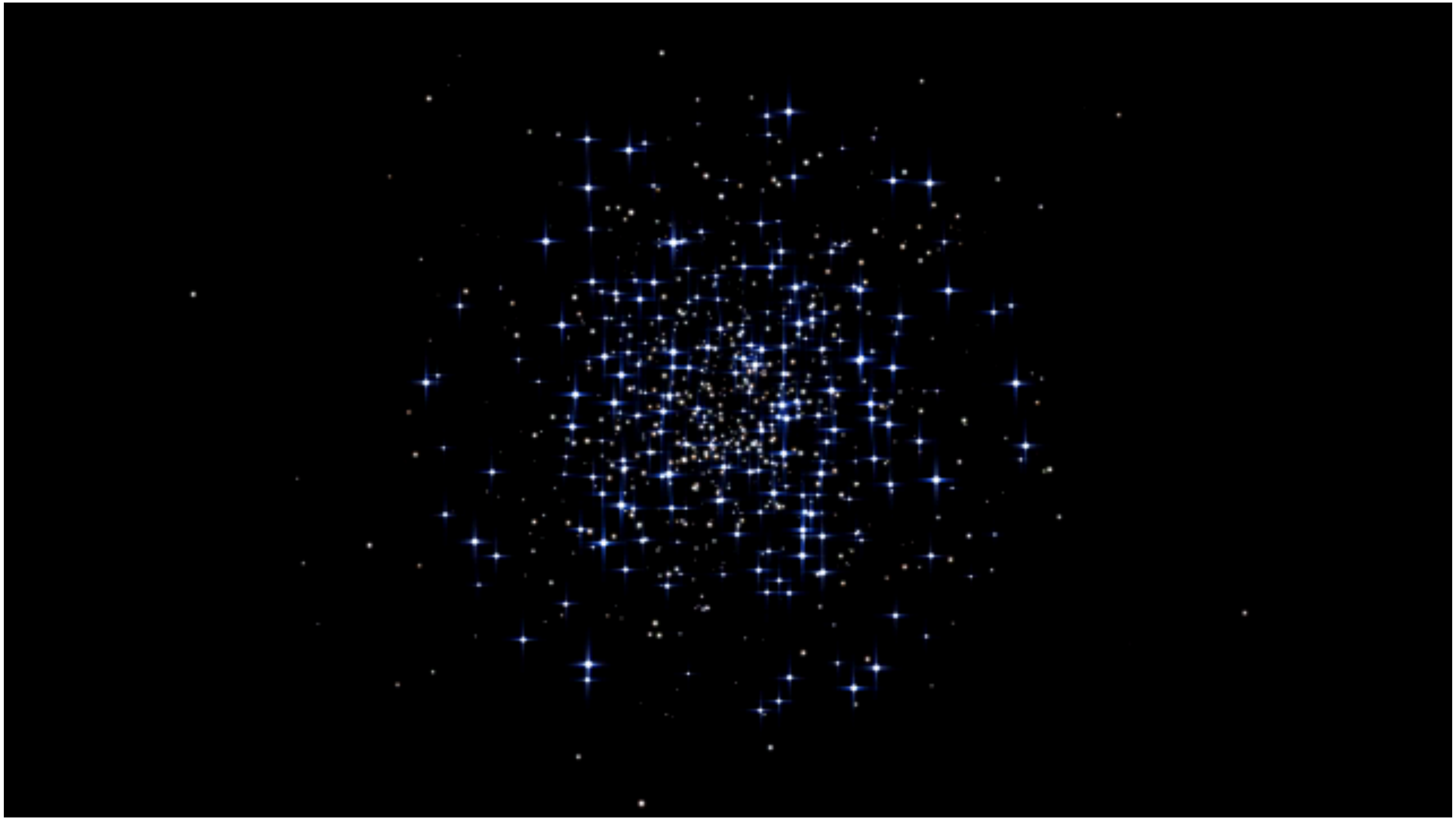
✦ AIM: **to understand the complex interplay between dynamics & stellar evolution**

✦ HOW: using **globular clusters** as cosmic laboratories and

Blue Straggler Stars
Millisecond Pulsars
Intermediate-mass Black Holes

} exotic objects as probe-particles

WHY GCs?

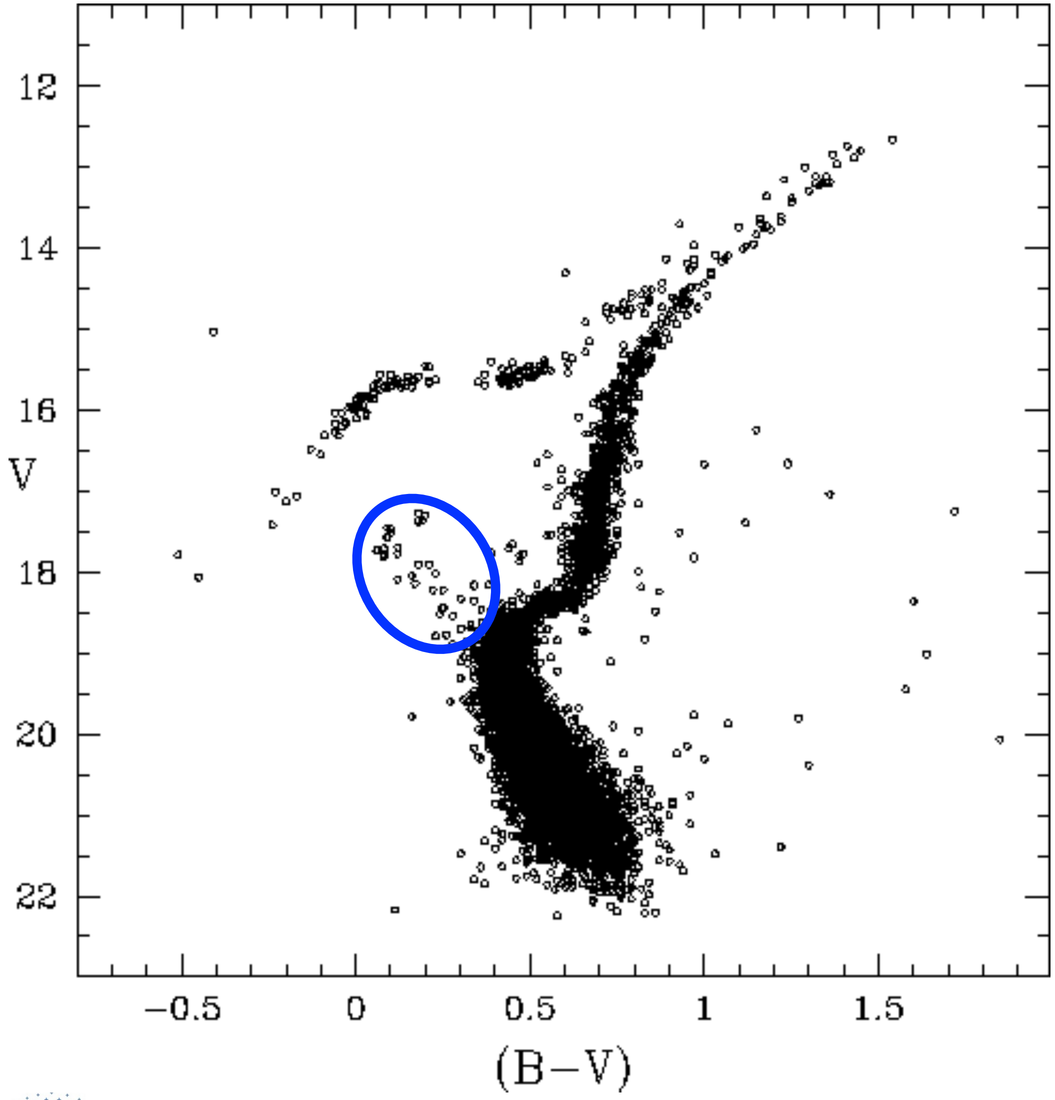


GC are the only stellar systems able to undergo nearly all the physical processes known in stellar dynamics over a time scale significantly shorter than the Hubble time.

This dynamical activity can generate **exotica**

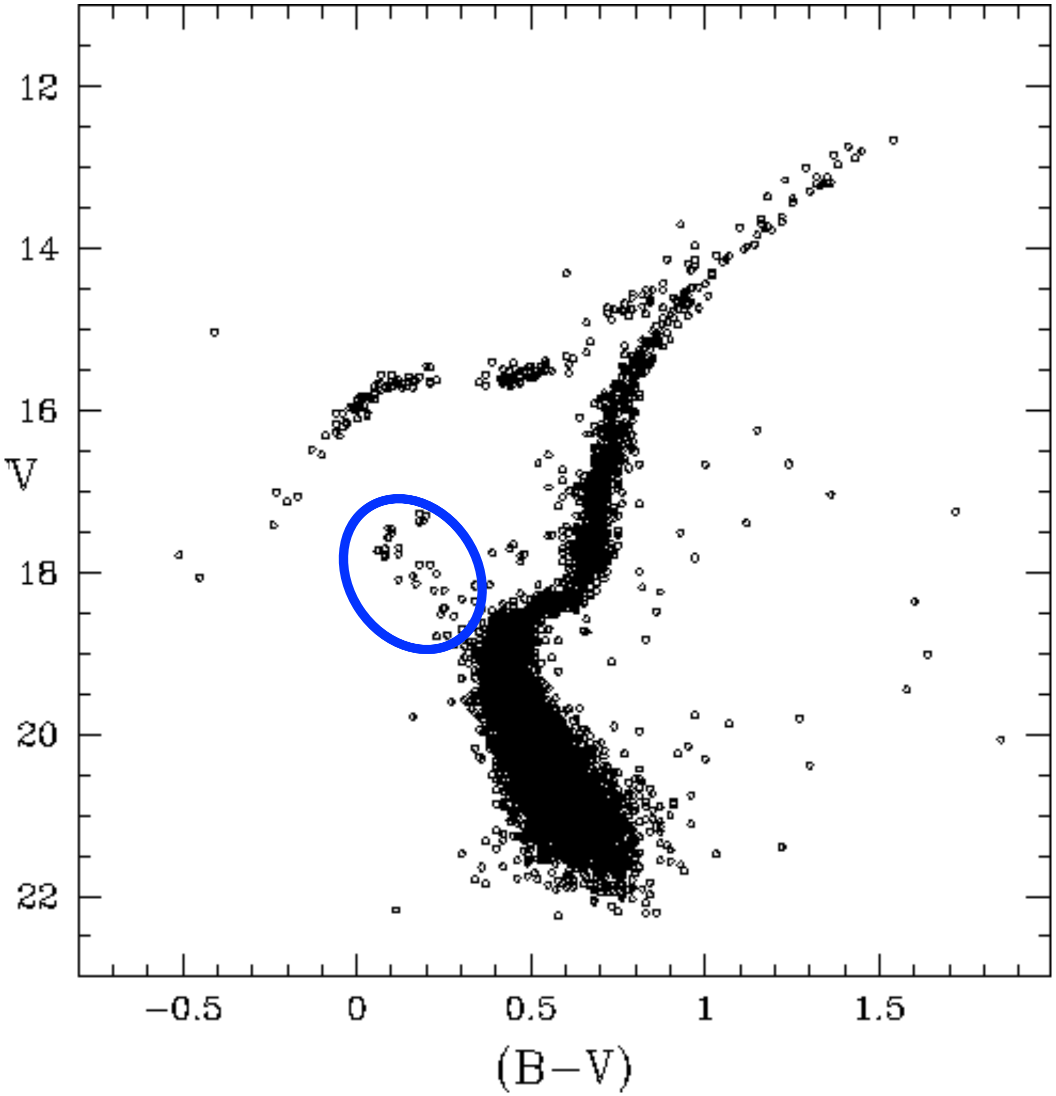
Blue Straggler Stars (BSS)

A stellar population rejuvenated by dynamical processes



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

Blue Straggler Stars (BSS)

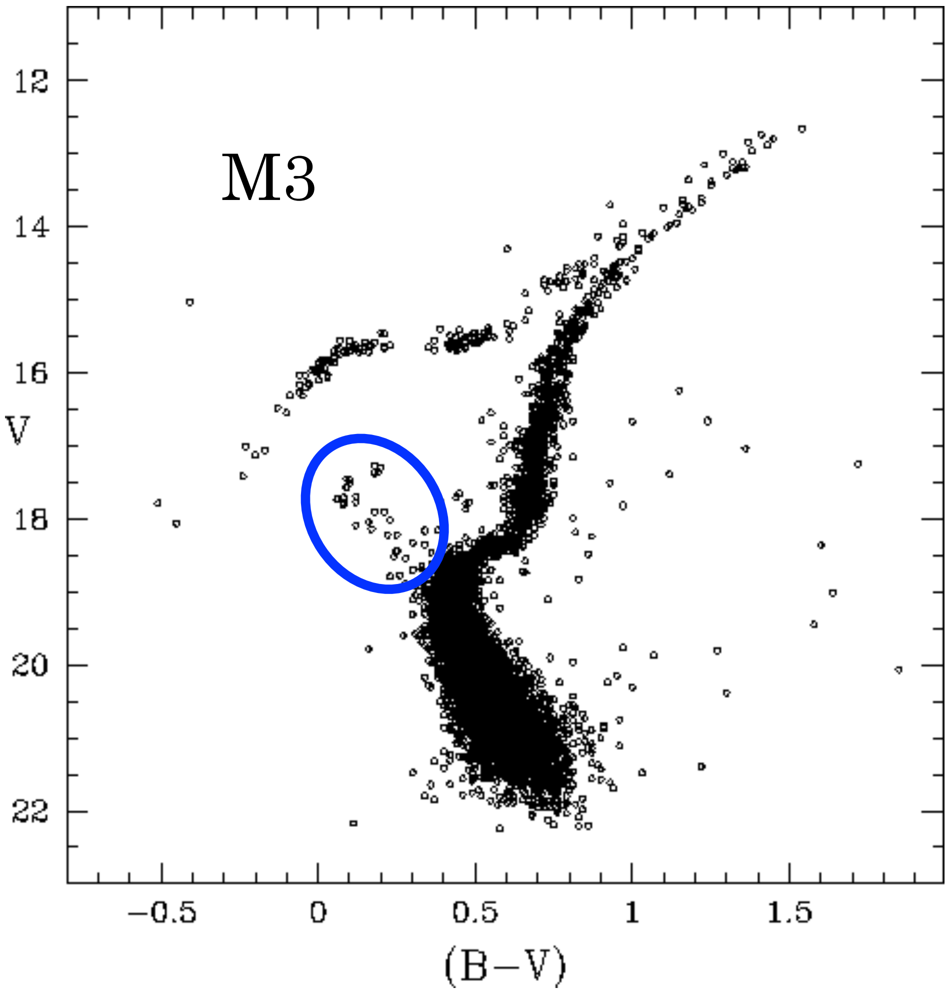


..while
old “normal” stars define
a sort of flock of tired stars
getting progressively
redder

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

Blue Straggler Stars (BSS)

Blue Straggler Stars (BSS)

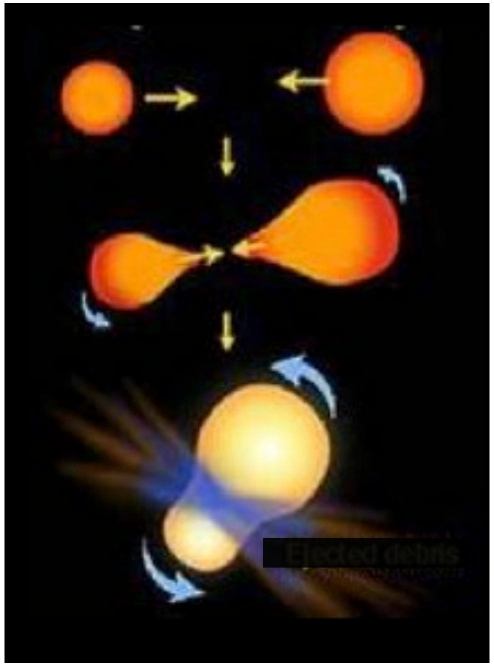


They LOOK younger but they are OLD stars rejuvenated by dynamical processes

Merger of two low-mass stars

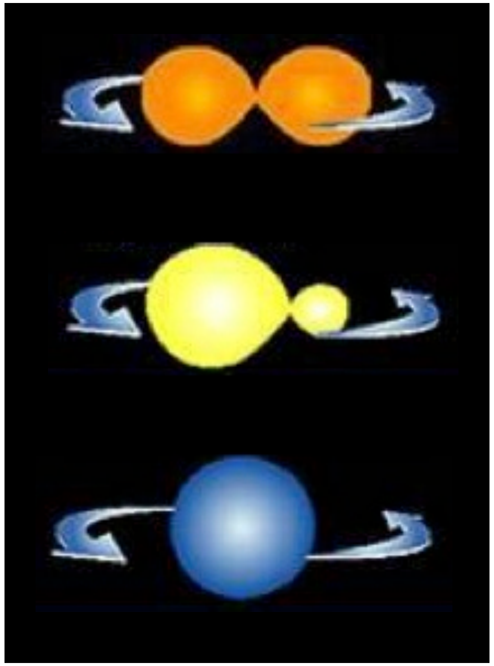
The formation mechanisms

COLLISIONS



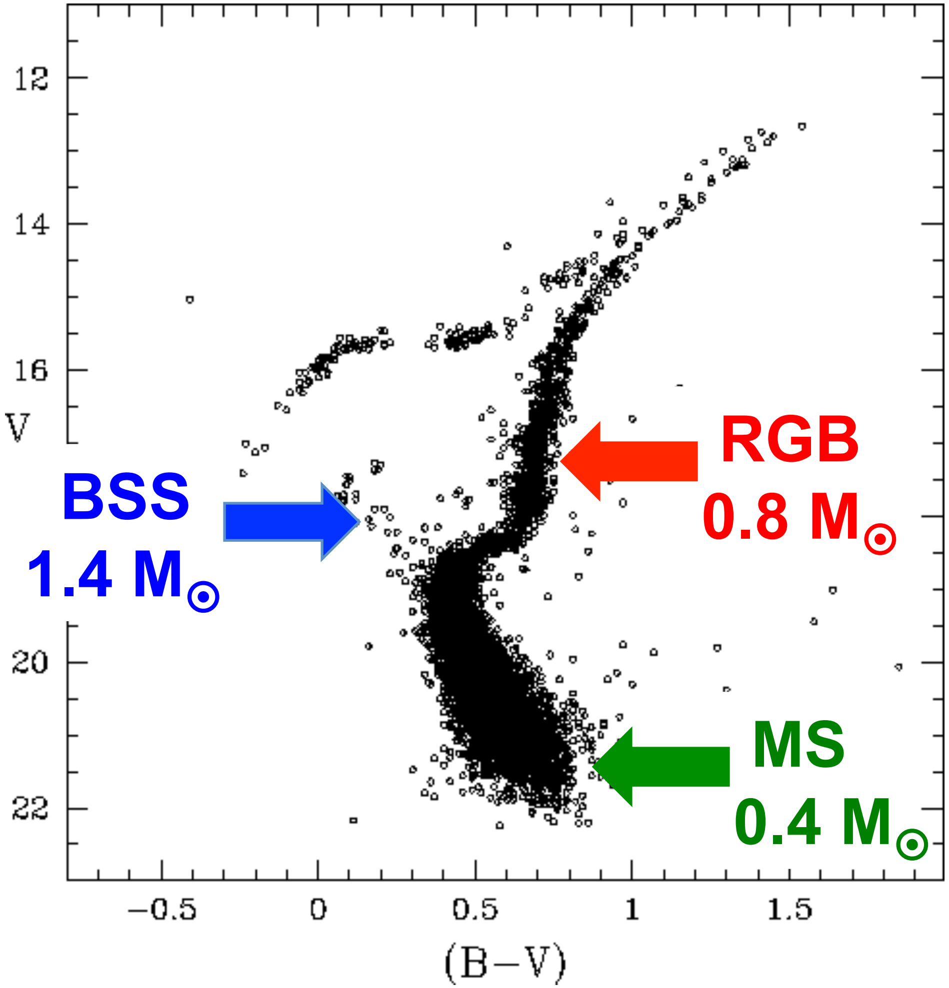
depend on **collision** rate
(Hills & Day 1976)

MASS-TRANSFER



depend on shrinking of binaries due to **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:

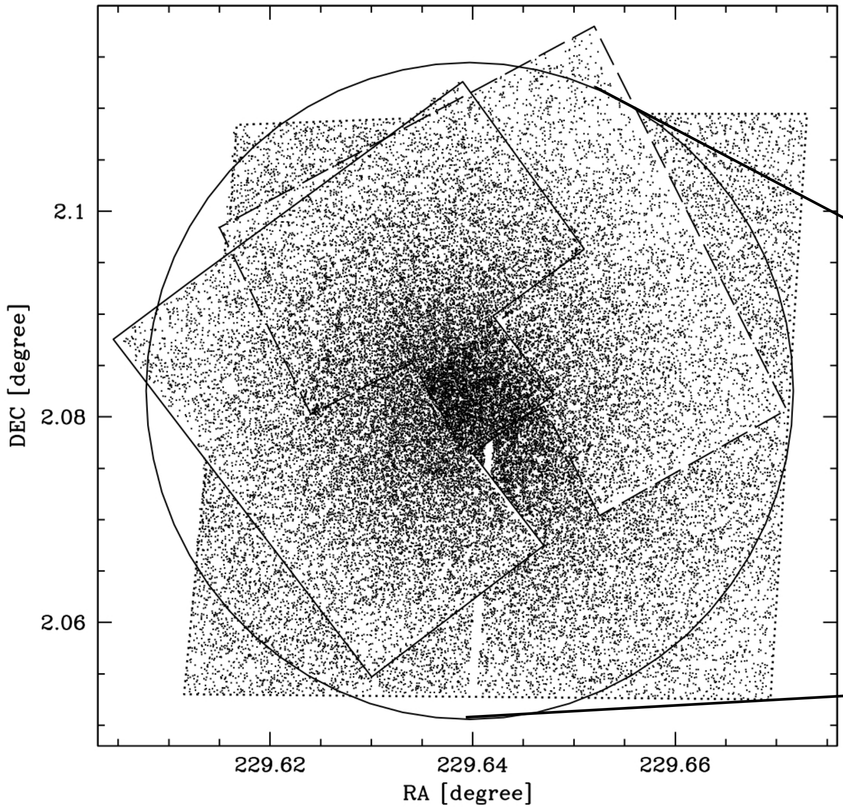
(1) Star mass **(2) Local cluster density**

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

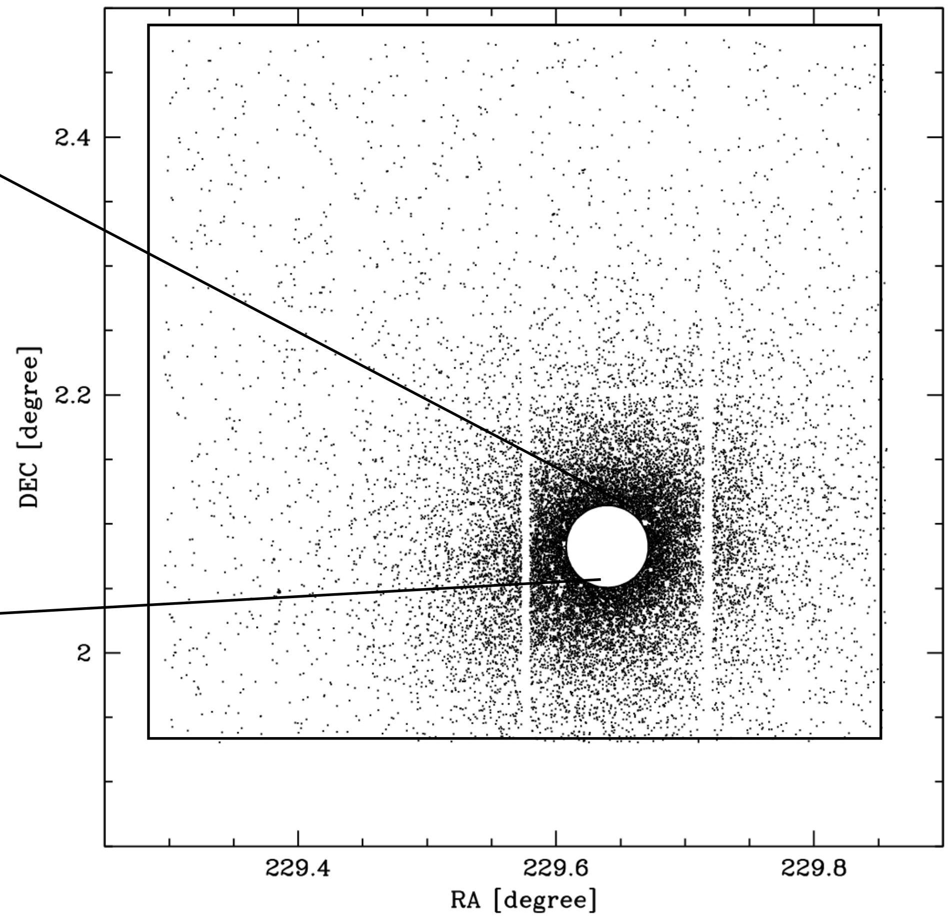
Because of this, **df** is expected to affect first the most internal BSS and then BSS progressively **at larger and larger distances,** as function of time

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

High-res: HST/WFPC2+ACS



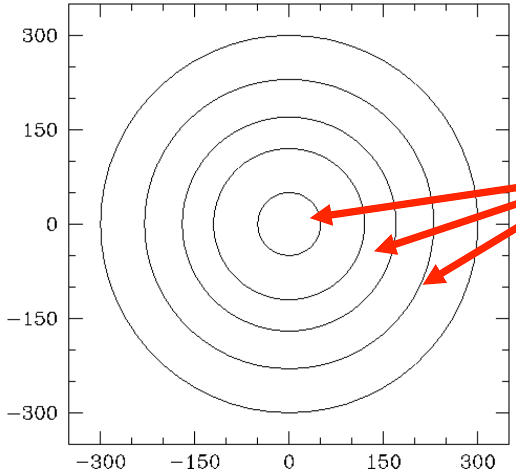
Wide-field ground-based imaging



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

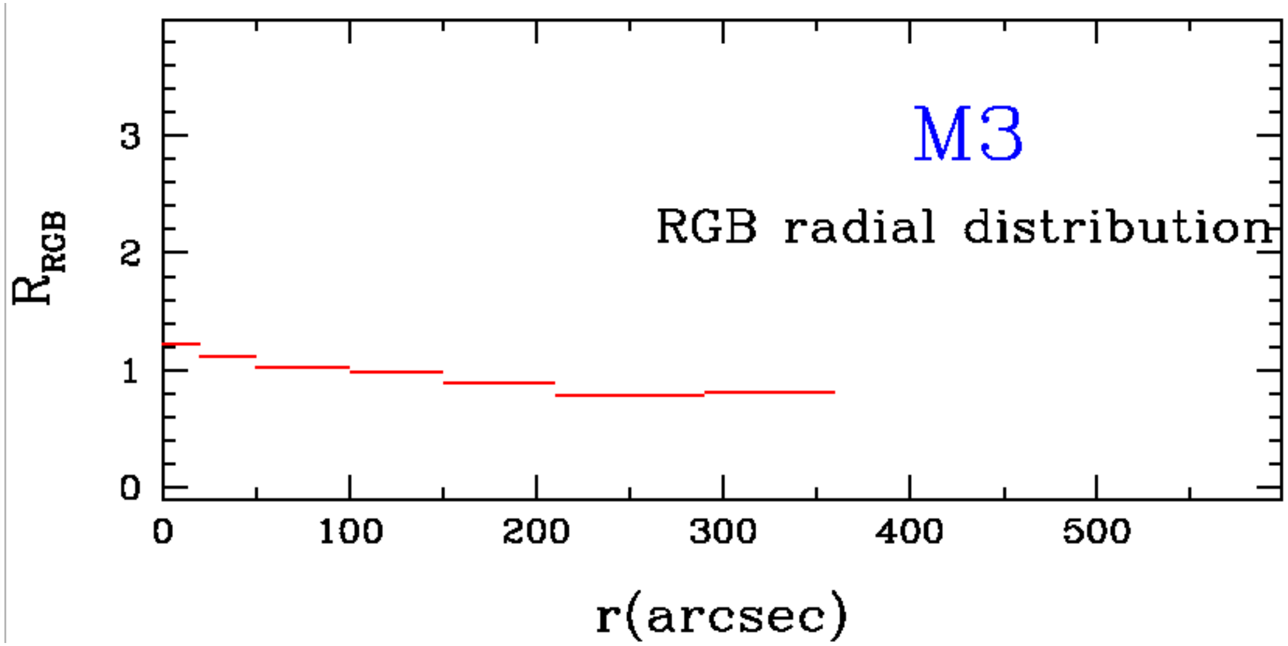
THE BSS RADIAL DISTRIBUTION



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

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"***



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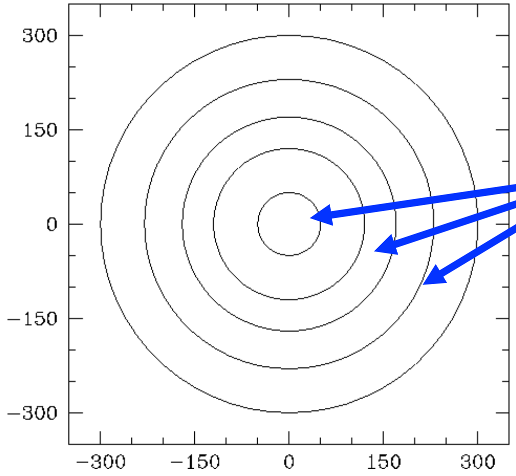
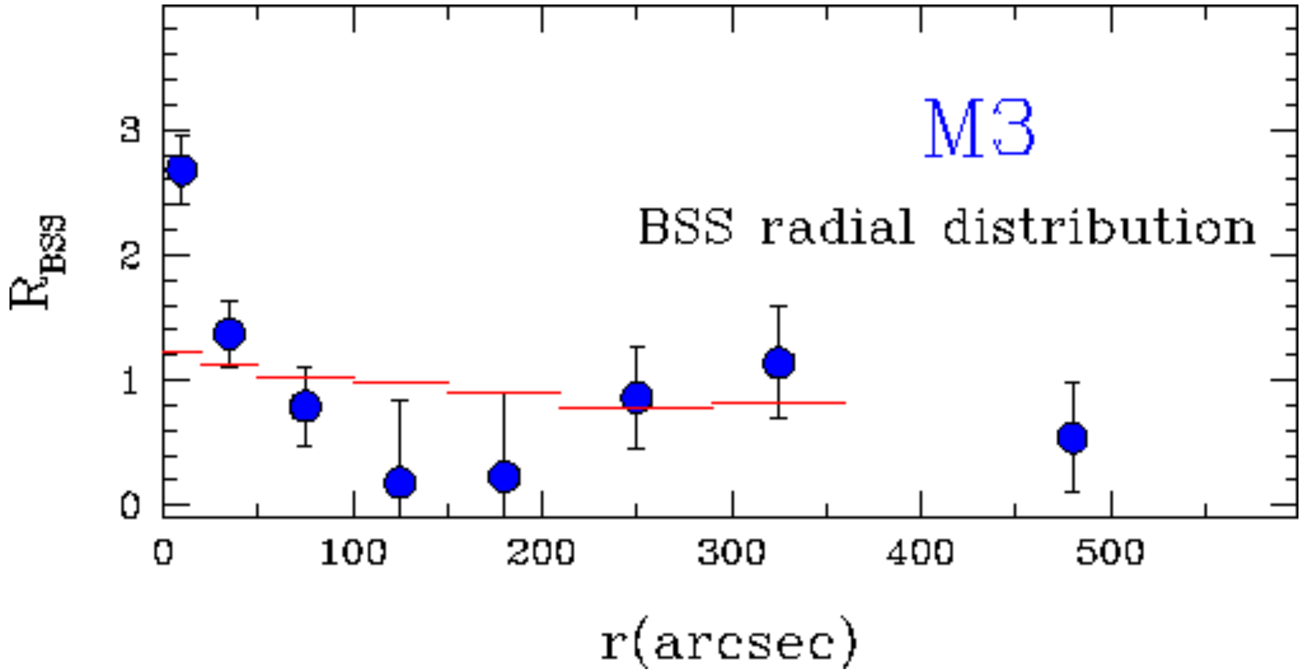
THE BSS RADIAL DISTRIBUTION

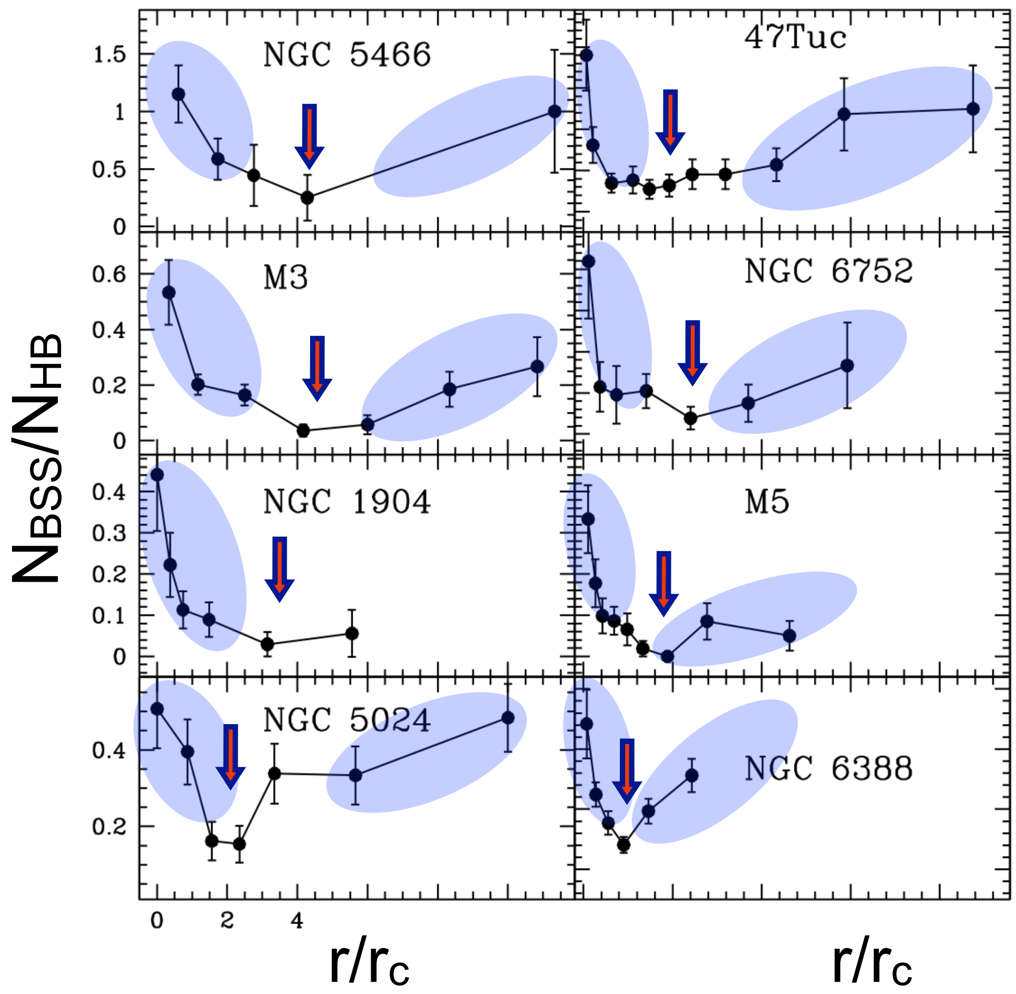


$$R_{BSS} = \frac{N_{BSS}/N_{BSS,TOT}}{L_{samp}/L_{TOT}}$$



BSS radial distribution

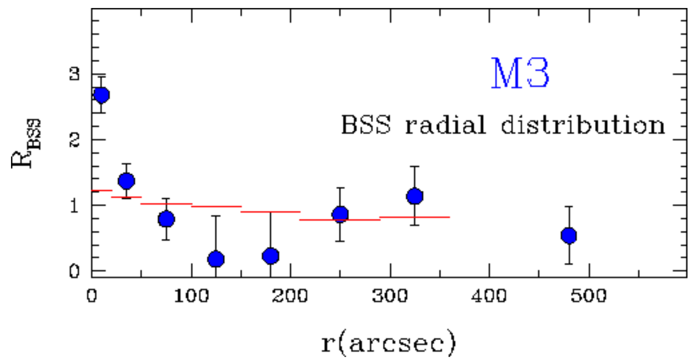
Over the last 15 years we studied the BSS radial distribution over the entire cluster extensions in 25 stellar systems. Finding a variety of cases



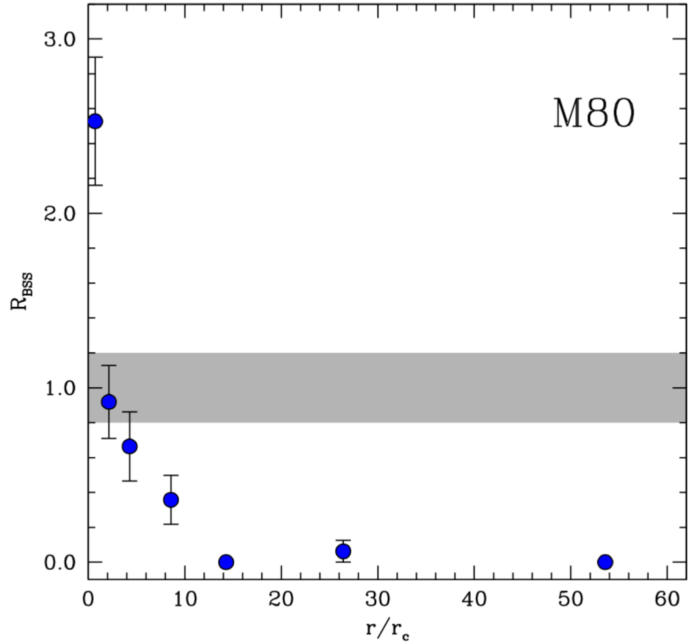
BSS radial distribution

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

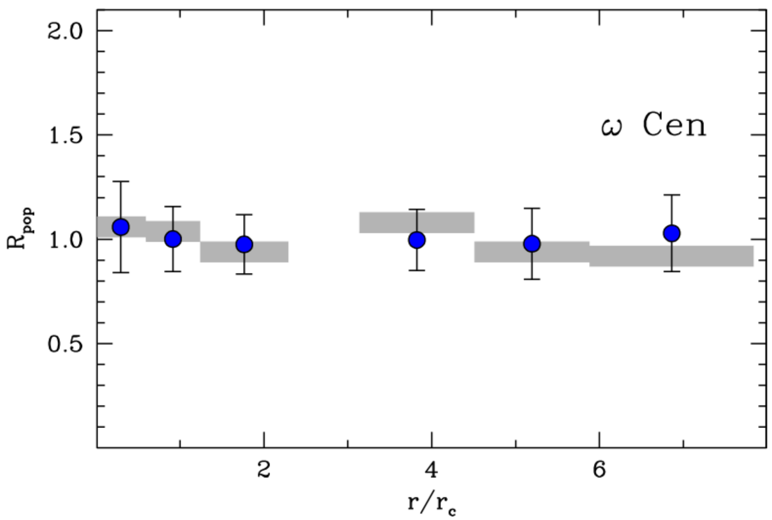
"bimodal"



"Unimodal" (single-peak)



"Flat"



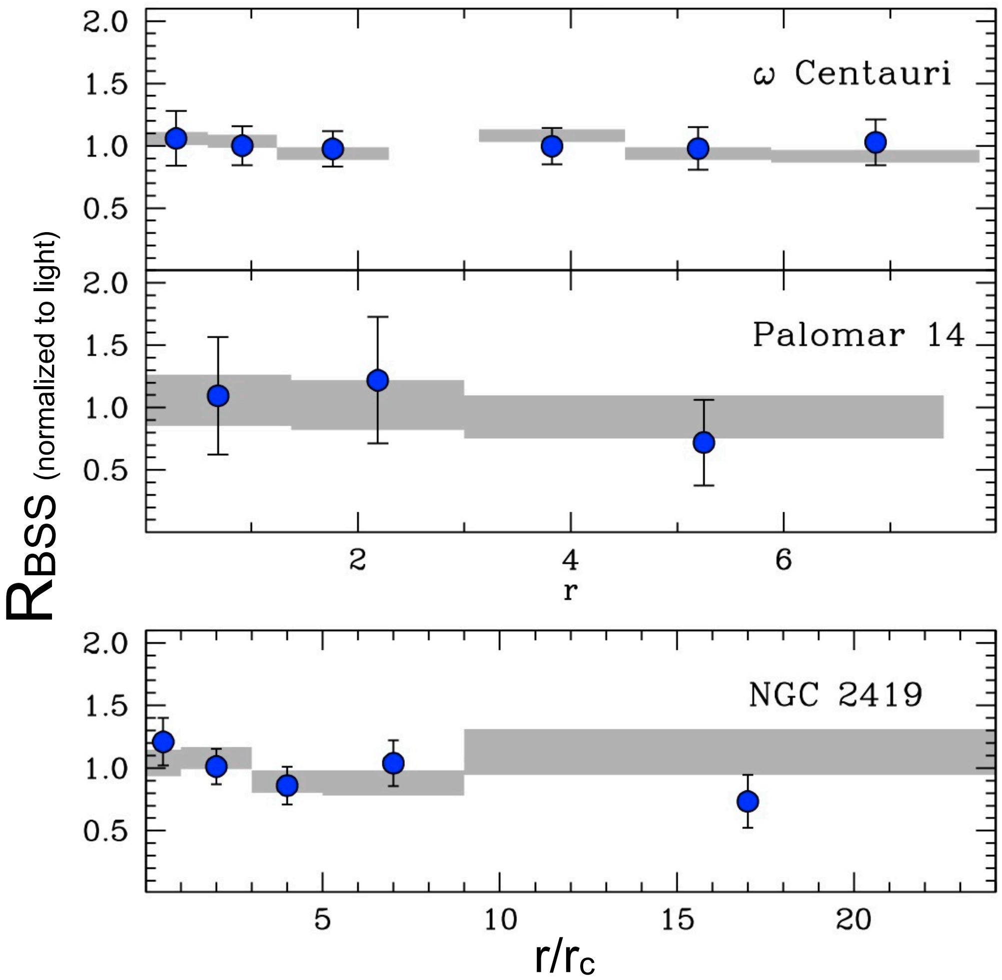
THE DYNAMICAL CLOCK

The BSS radial distribution is shaped by the dynamical friction, which progressively segregates BSS over the cluster age (~ Hubble time)

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

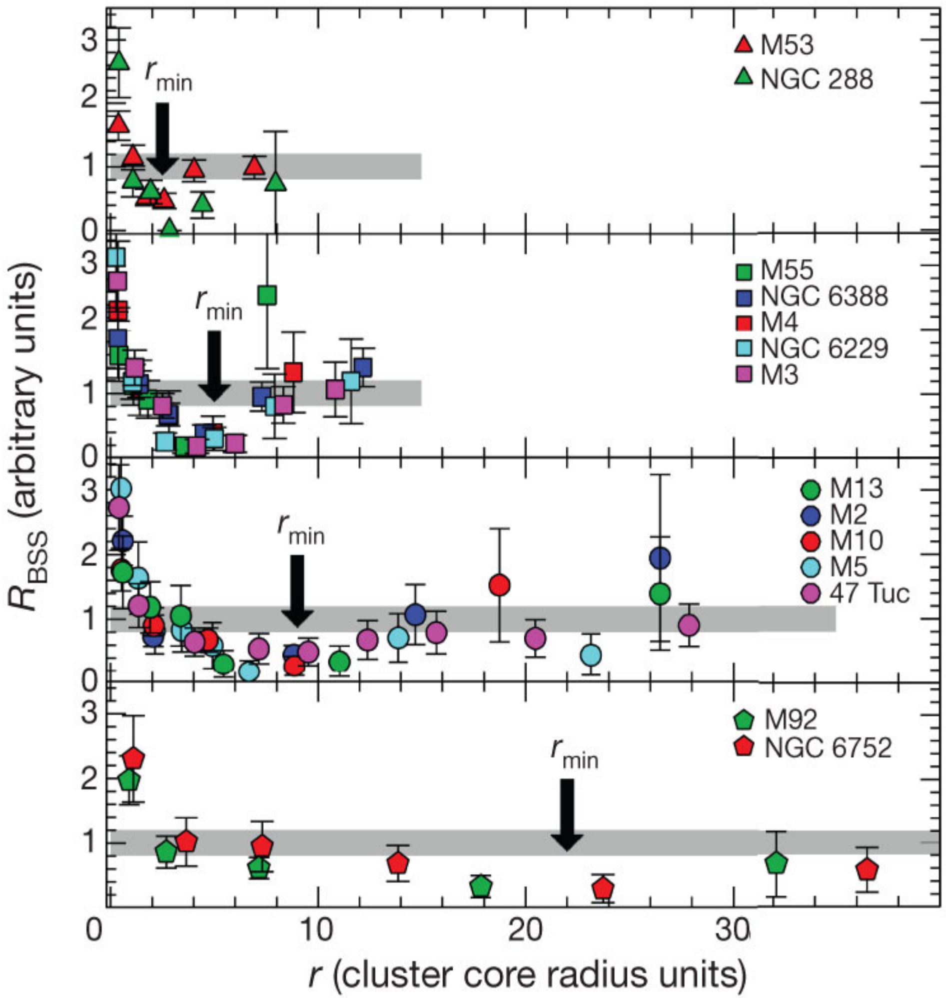
Note that this is the **most efficient way** to prove that these stellar systems are not relaxed yet

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

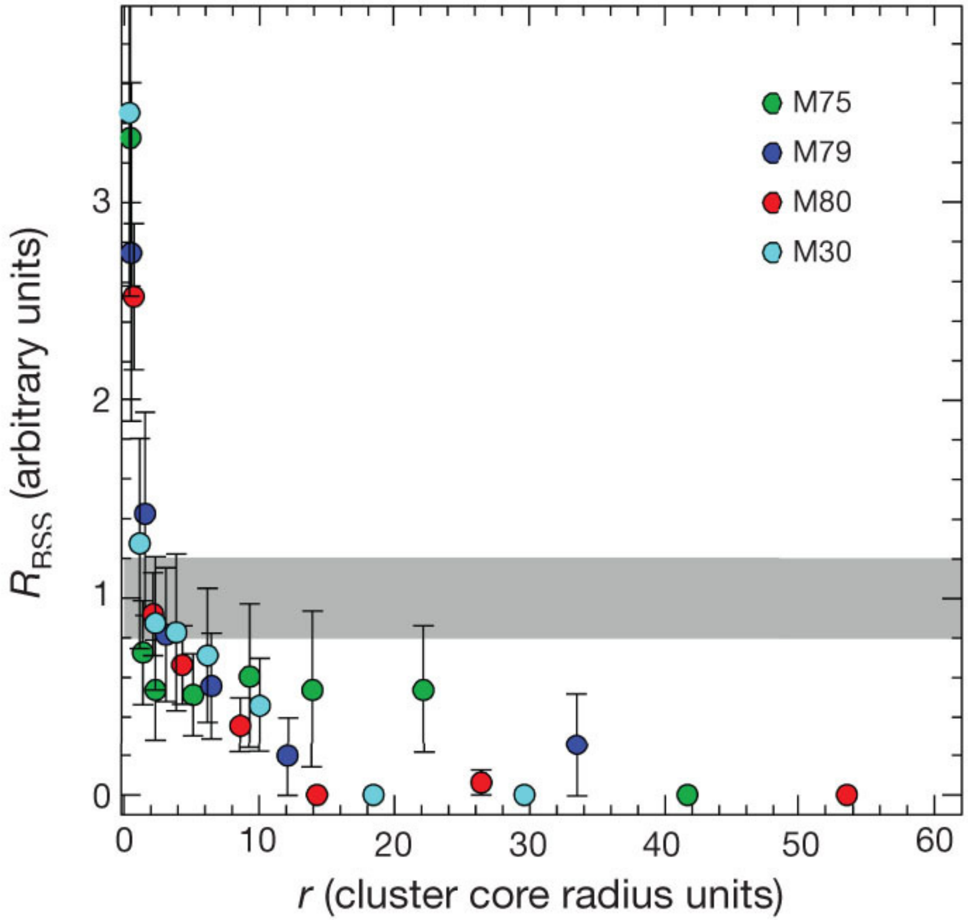
The action of **df** extends progressively at larger distances from the cluster center = the minimum is moving progressively outward

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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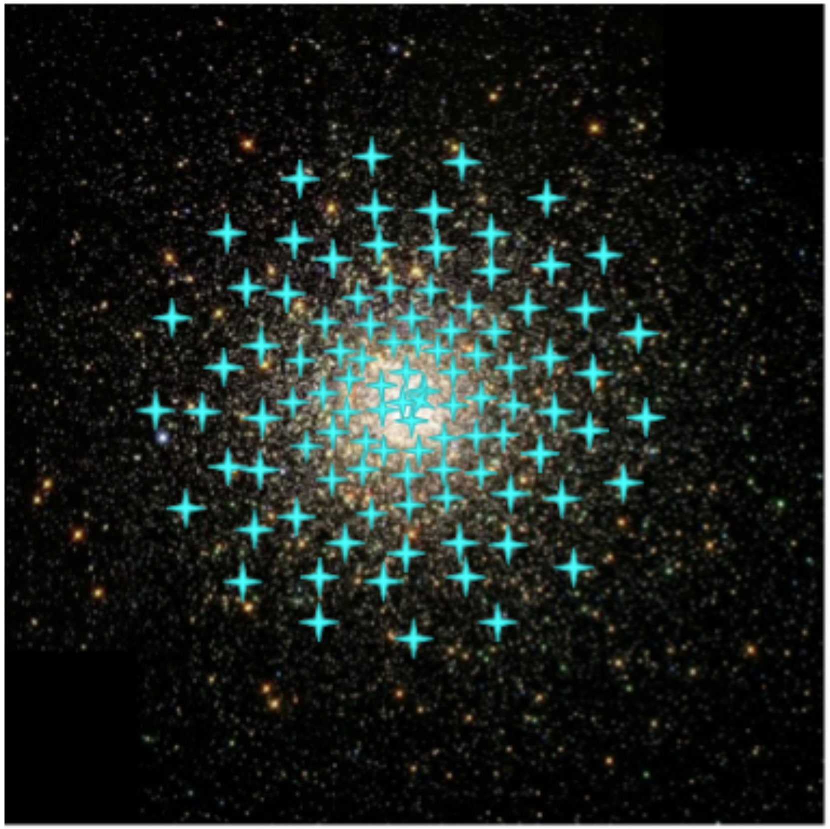
The dynamical clock

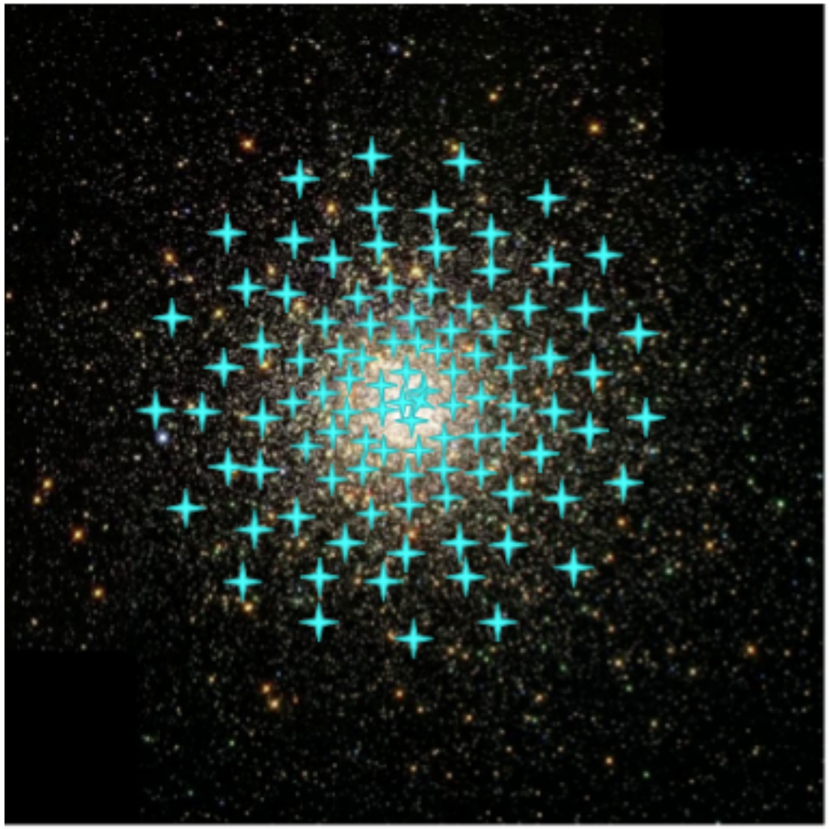
Ferraro et al (2012,Nature,492,393)



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

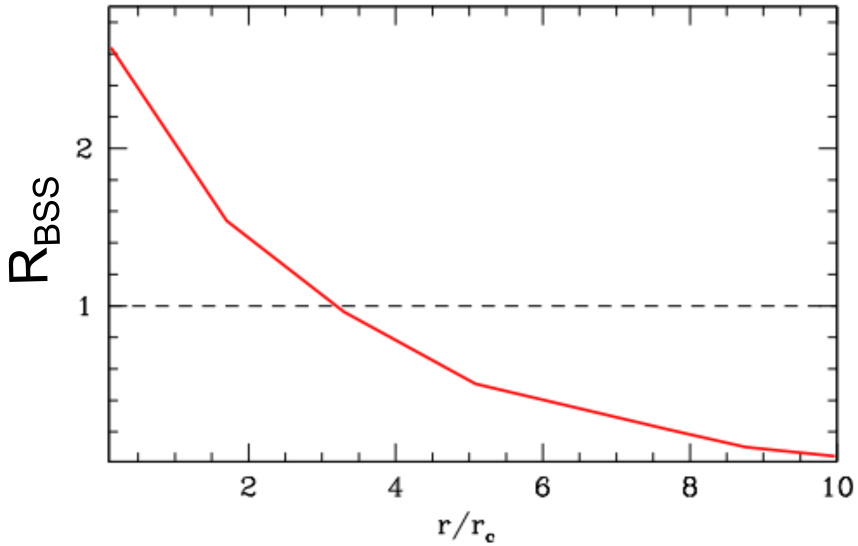
Ferraro et al (2012,Nature,492,393)



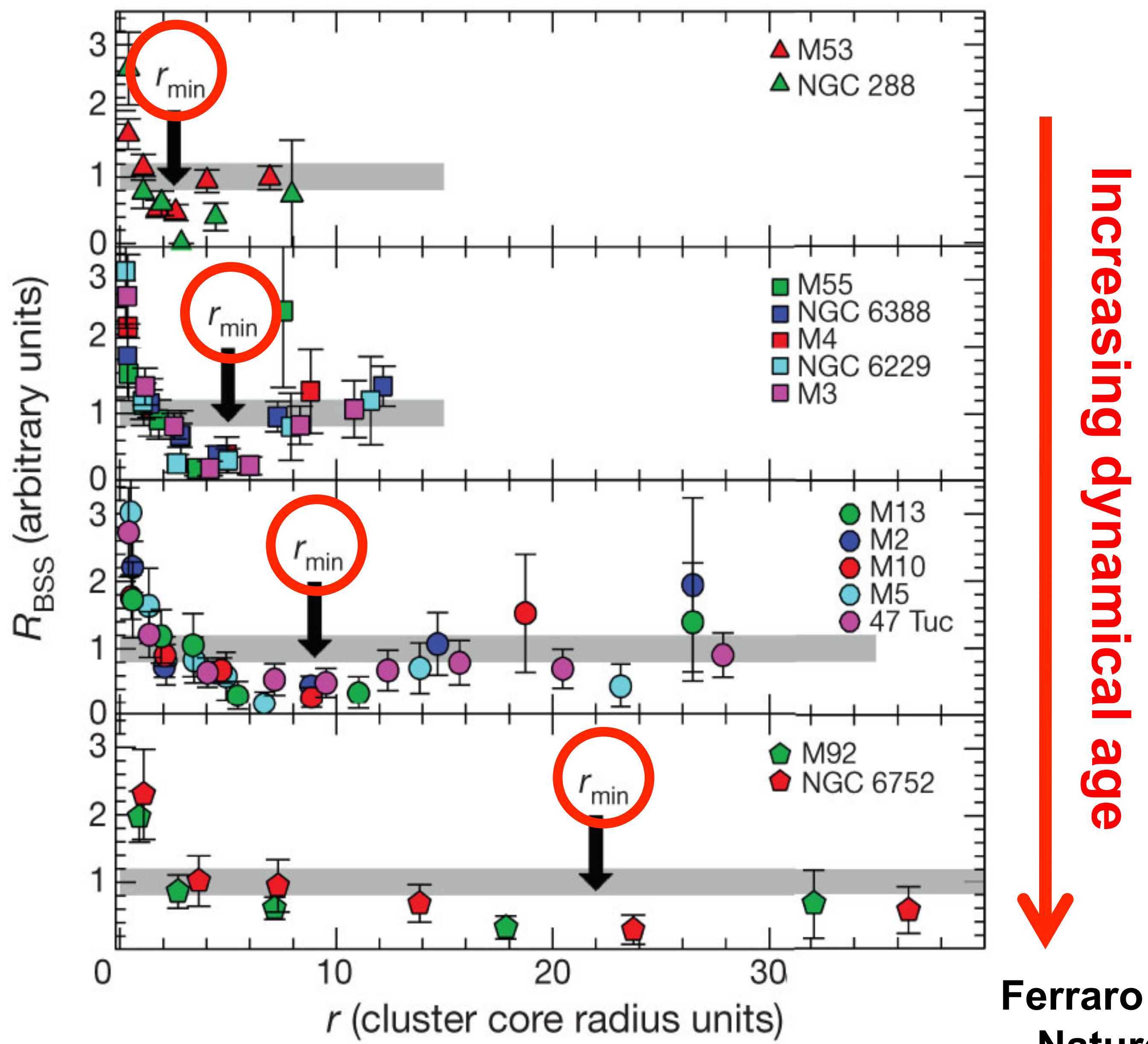
The cartoon illustrates the action of the **df** that progressively segregates the BSS toward the cluster center producing a **dip in the radial distribution** that propagates toward the external region as a function of the time.

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

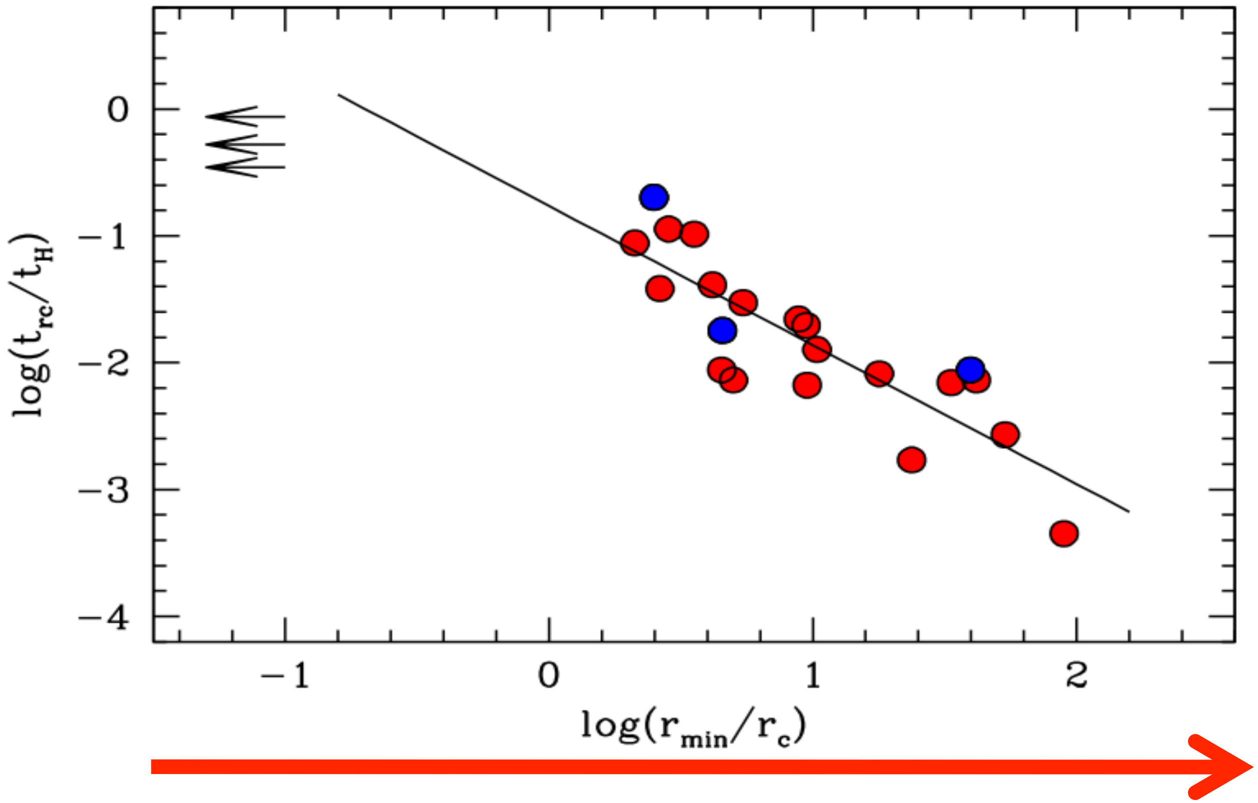


Ferraro et al 2012, Nature,492,393

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

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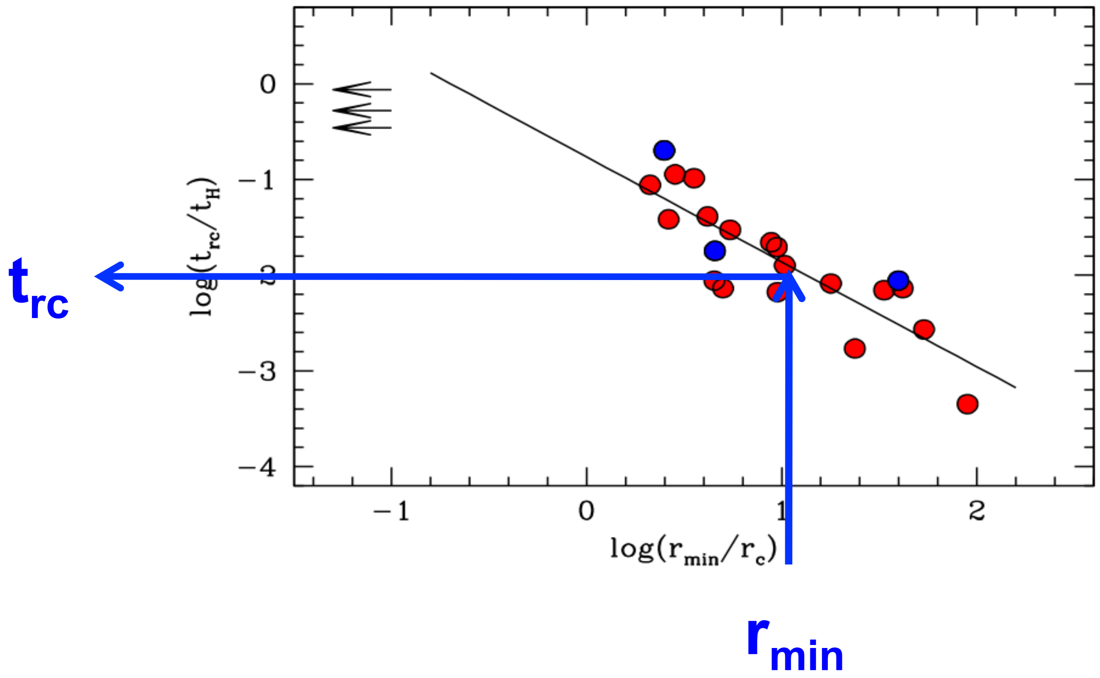
The dynamical clock

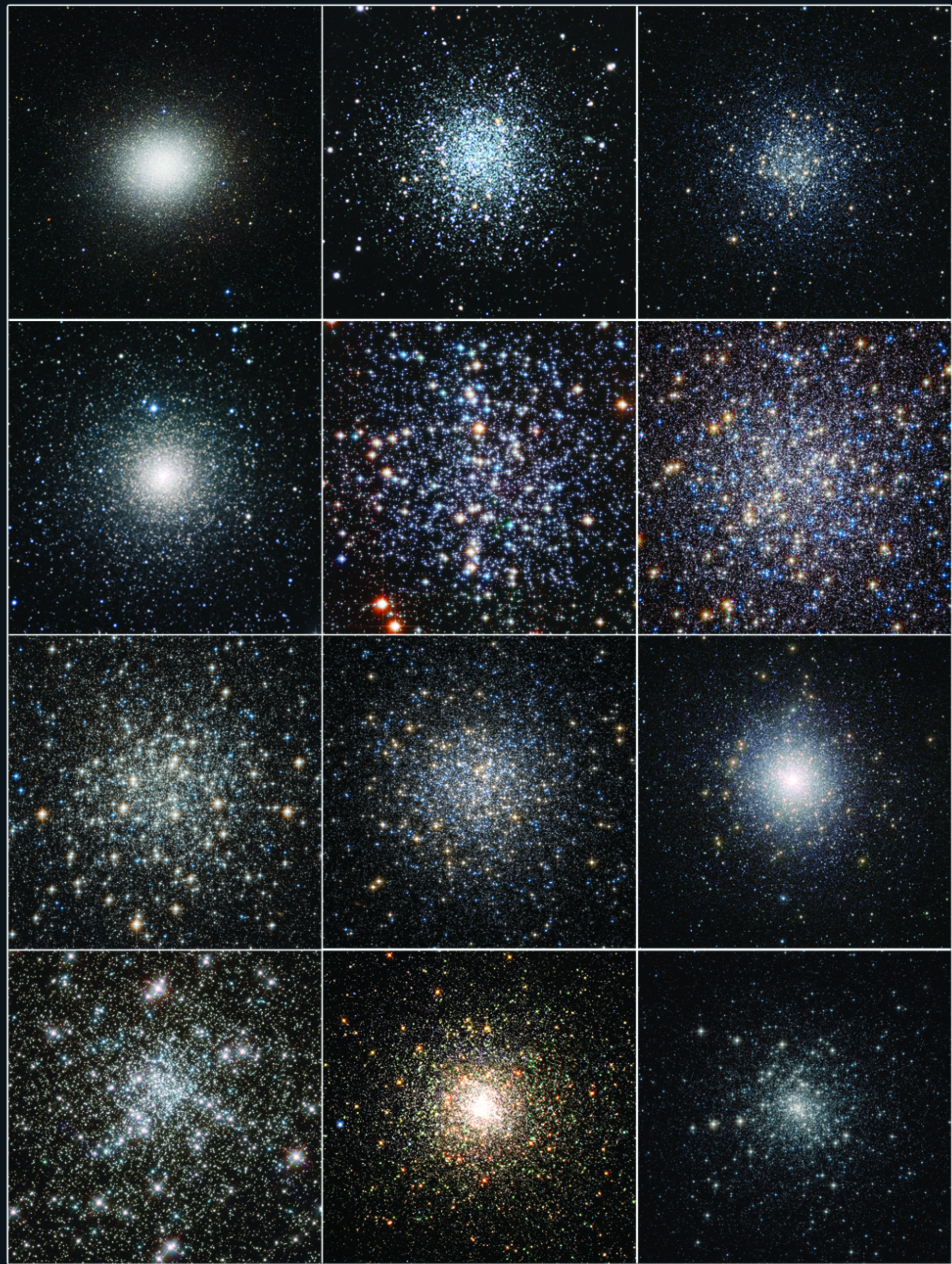
Ferraro et al (2012,Nature,492,393)

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



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

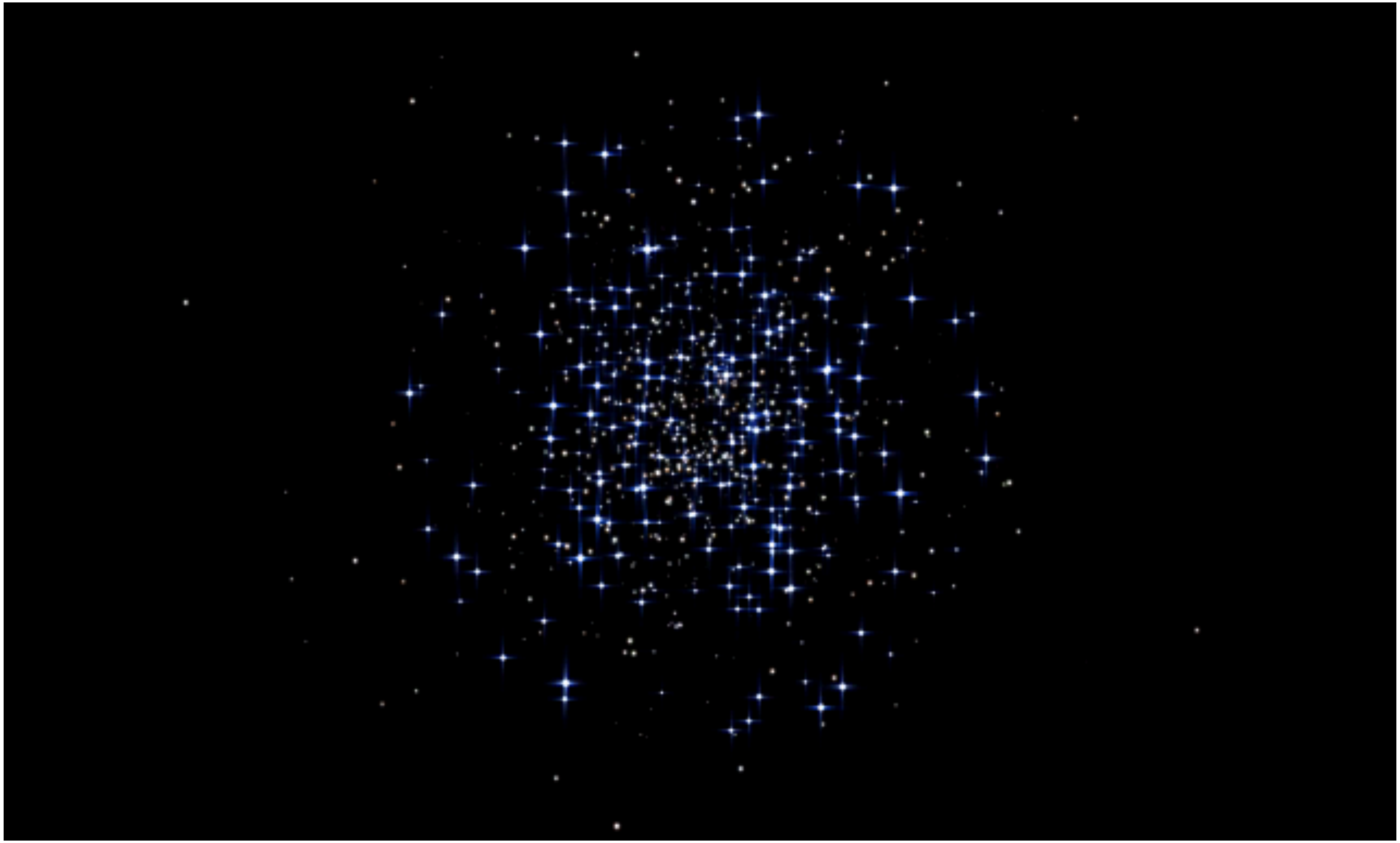


Mosaic of 12 images of Milky Way globular clusters ranked in order of increasing dynamical age, as measured by the "dynamical clock of stellar systems".
From top-left, to bottom-right: omegaCentauri, NGC 288, M55, NGC 6388, M4, M13, M10, M5, 47 Tucanae, NGC 6752, M80, and M30.

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).

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 !!!

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The End