An empirical clock to measure the dynamical age of stellar systems

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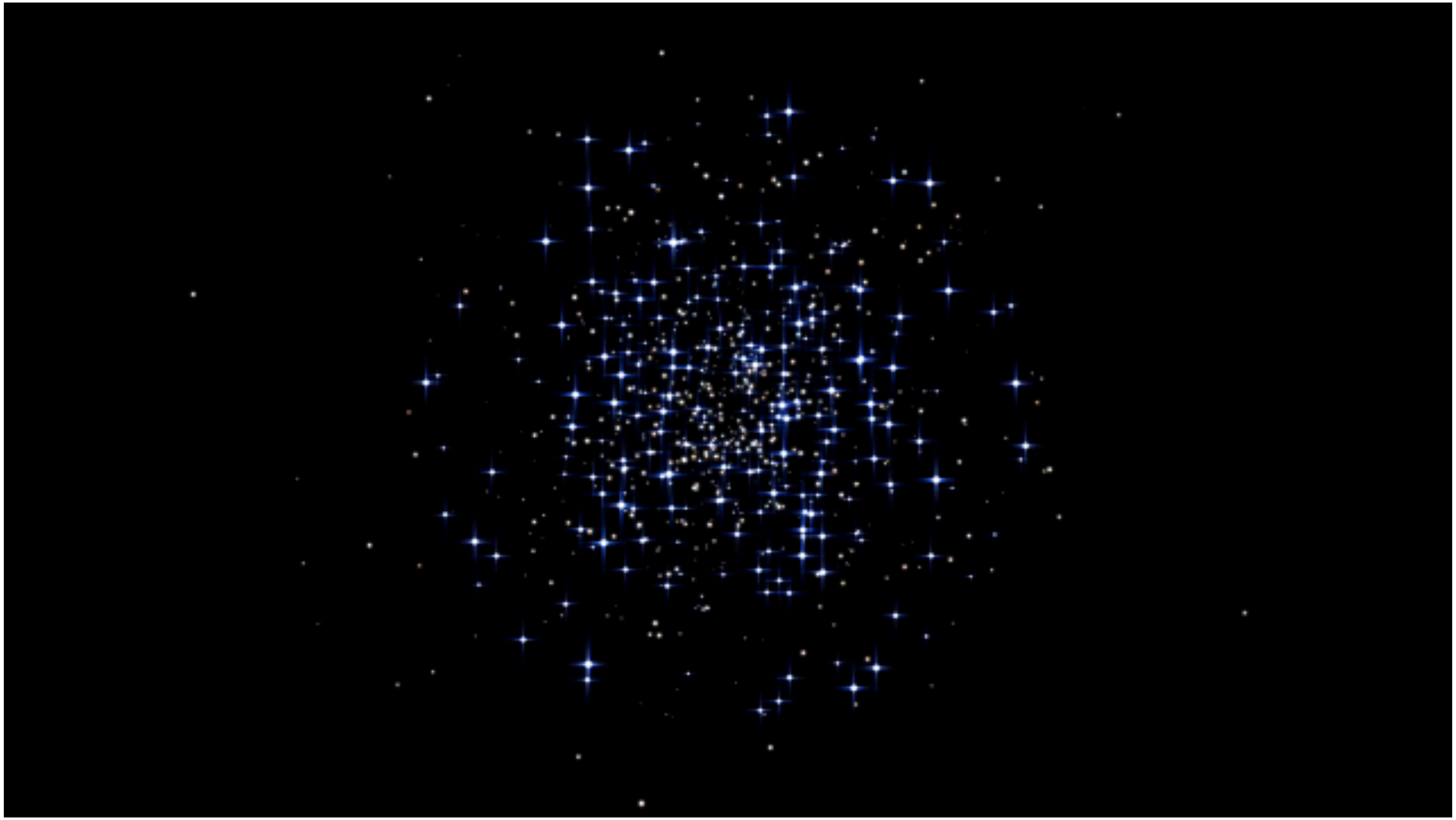
Cosmic-Lab

- 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?

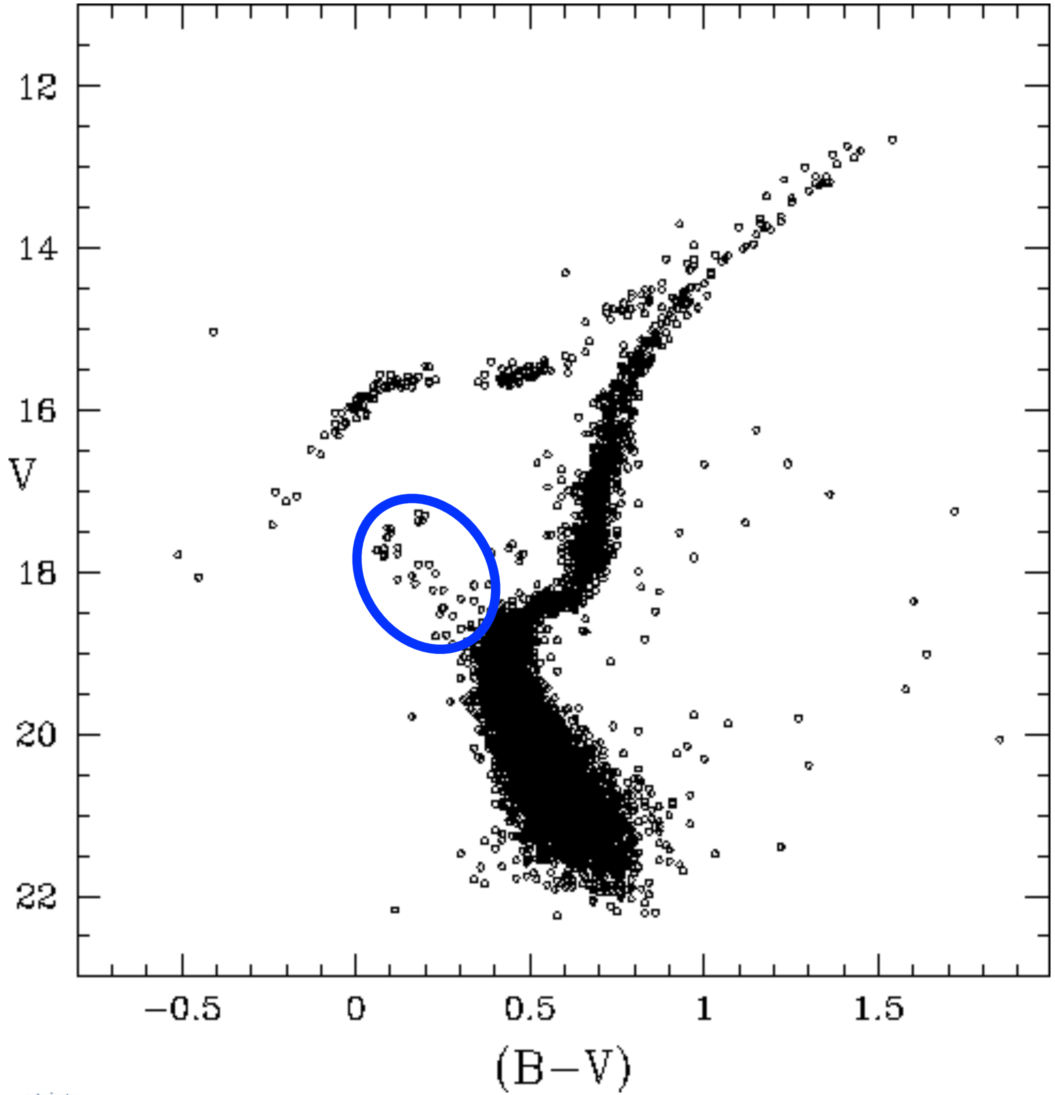


GC are the only stellar systems able to undergo nearly all the physical processes known in stellar dynamics over a time scale significantly shorter than the Hubble time.

This dynamical activity can generate **exotica**

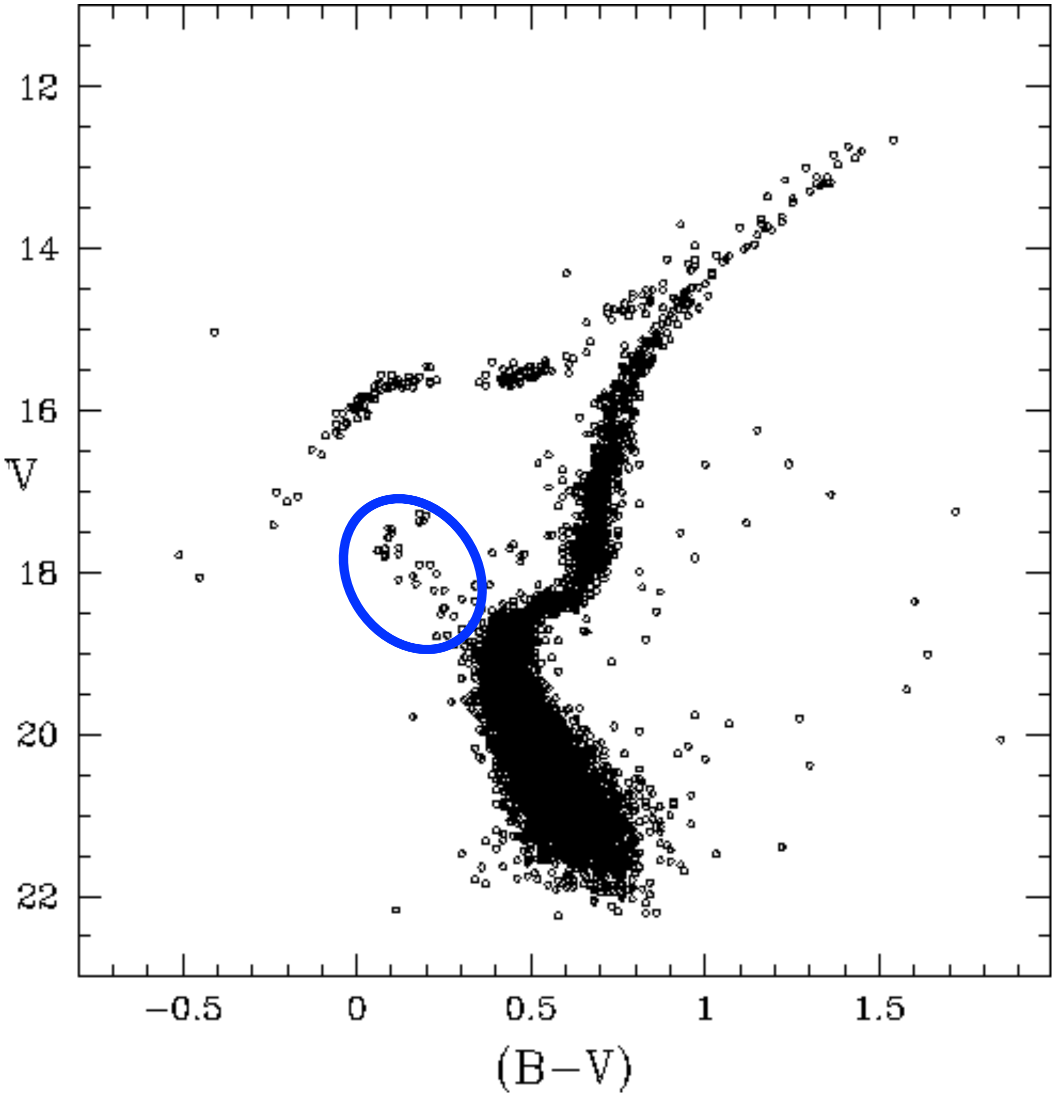
Blue Straggler Stars (BSS)

A 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)

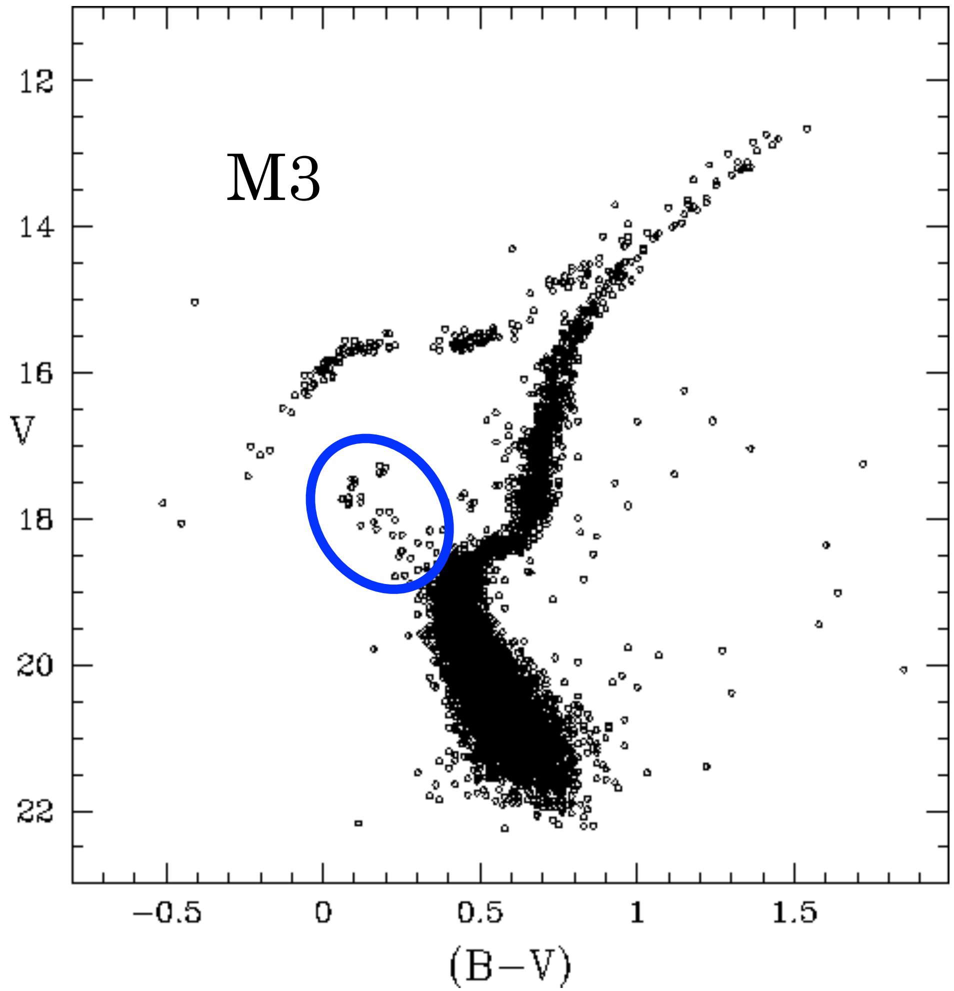


..while
old "normal" stars define
a sort of flock of tired stars
getting progressively
redder

BSS appear as a bunch
of "apparently" younger
blue stars

Blue Straggler Stars (BSS)

Blue Straggler Stars (BSS)

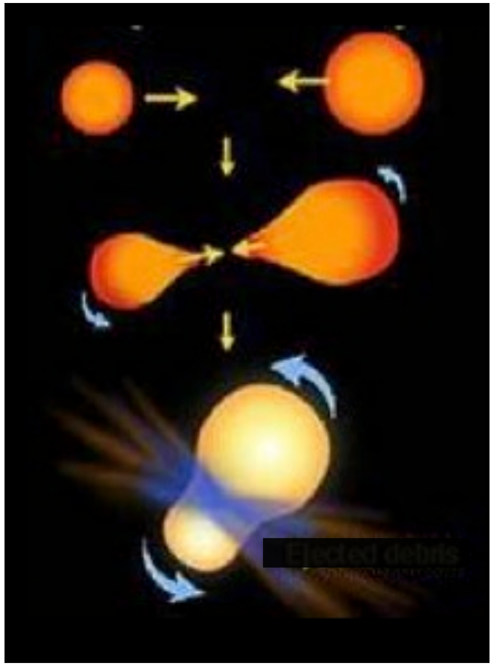


They LOOK younger but they are OLD stars rejuvenated by dynamical processes

Merger of two low-mass unevolved stars

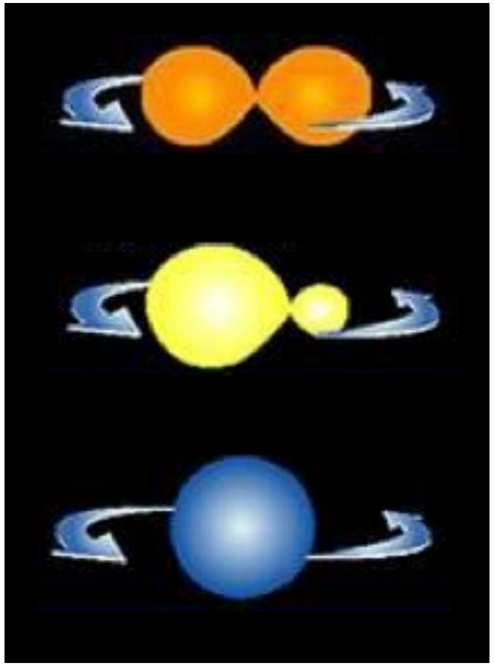
The formation mechanisms

COLLISIONS



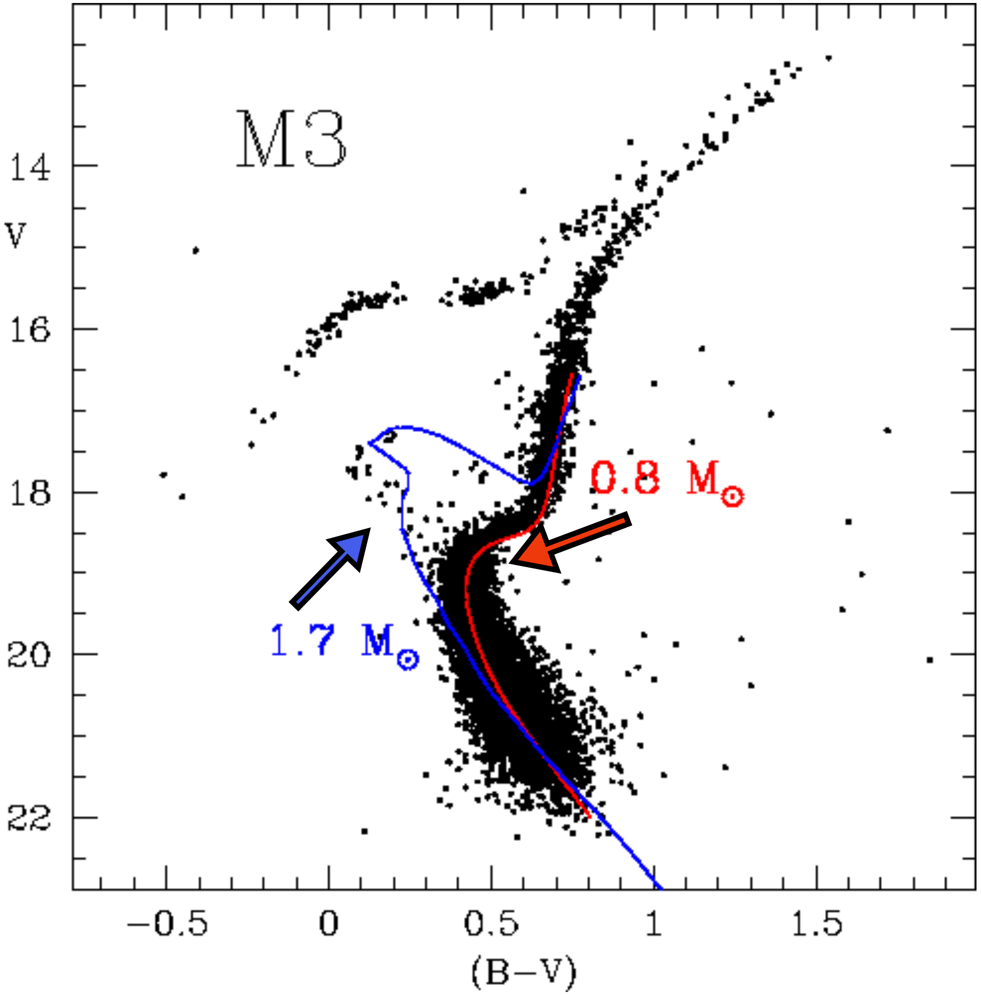
depend on **collision** rate
(Hills & Day 1976)

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

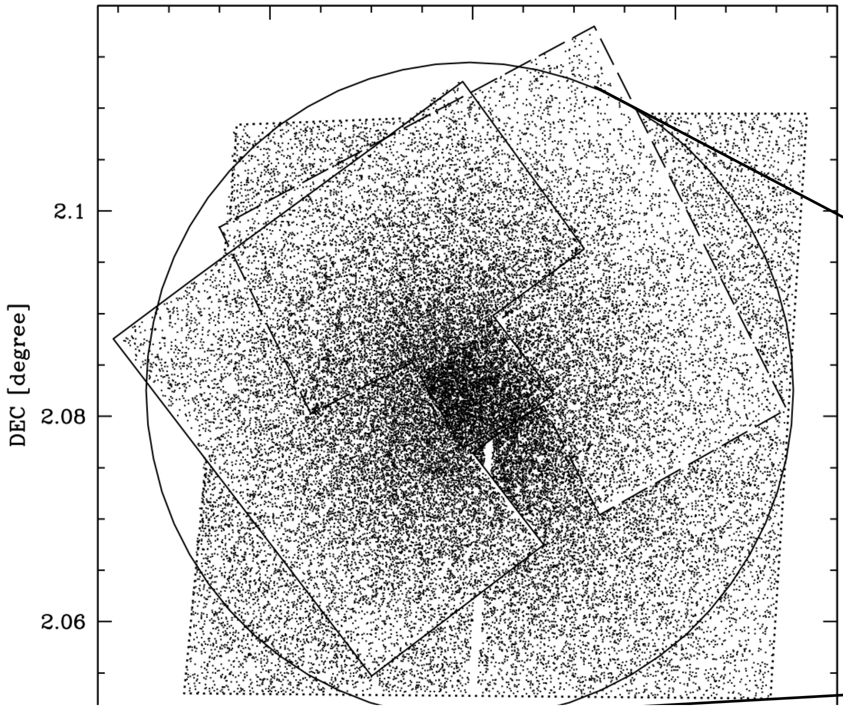
BSS are heavy stars (M_{BSS}=1.2-1.4 $M_{\odot}$) orbiting in a “sea” of “normal” light stars (M_{mean} =0.4 $M_{\odot}$): they are subject to **dynamical friction** that progressively makes them sink toward the cluster center

$$t_{df} = \frac{3\,\sigma^3(r)}{4\,\ln\Lambda\, G^2\, (2\pi)^{1/2}\, M_{BSS}\, \rho(r)}$$

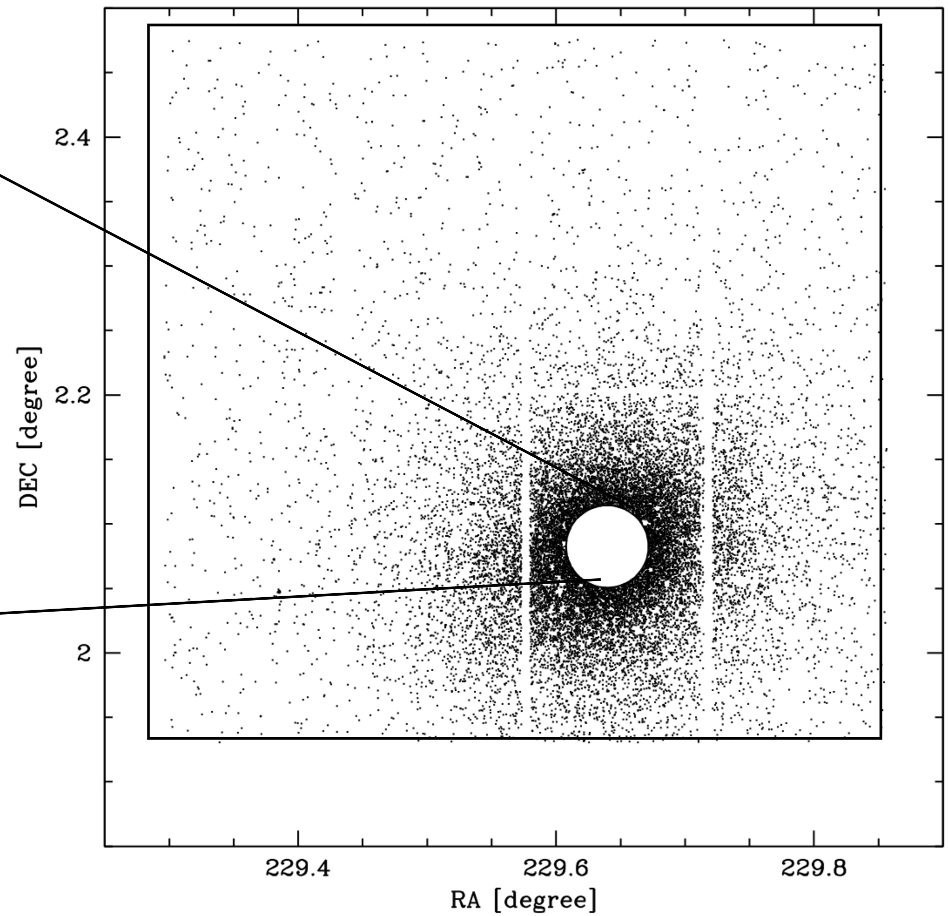
Because of the sensitivity of the **df** time-scale to the cluster local density, **df** is expected to affect first the most internal BSS and then BSS progressively **at larger and larger distances,** as function of time

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

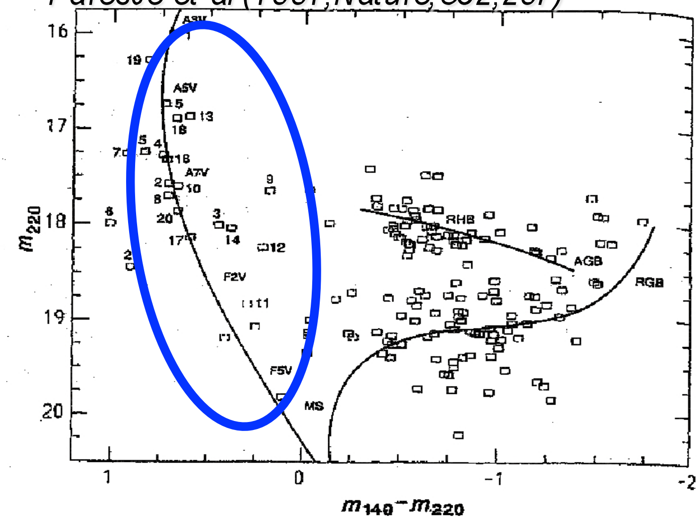
High-res: HST/WFPC2+ACS



Wide-field ground-based imaging



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



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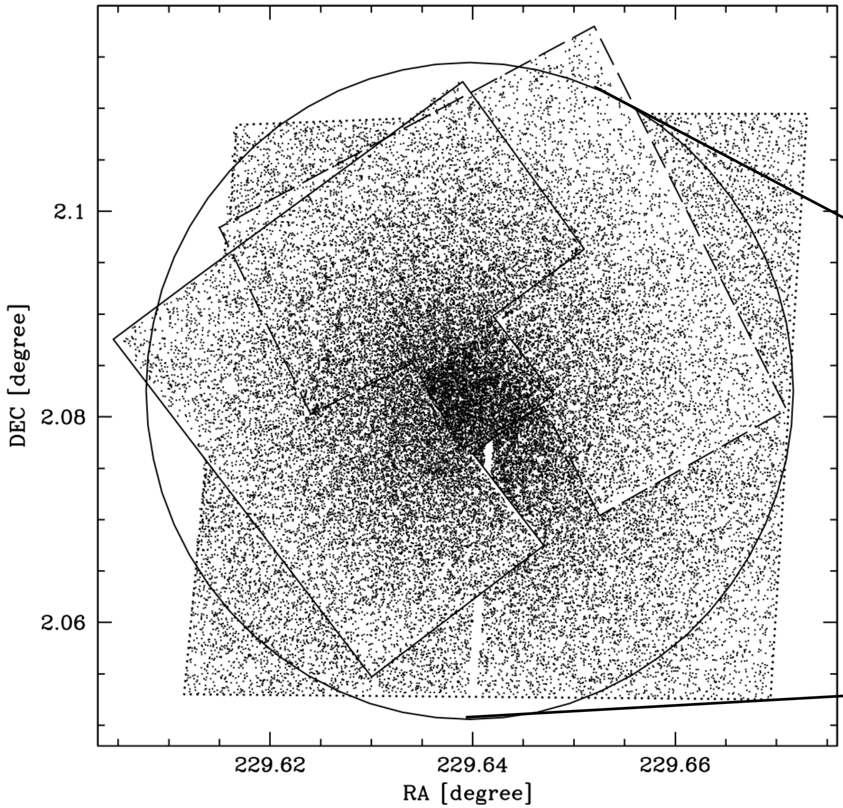
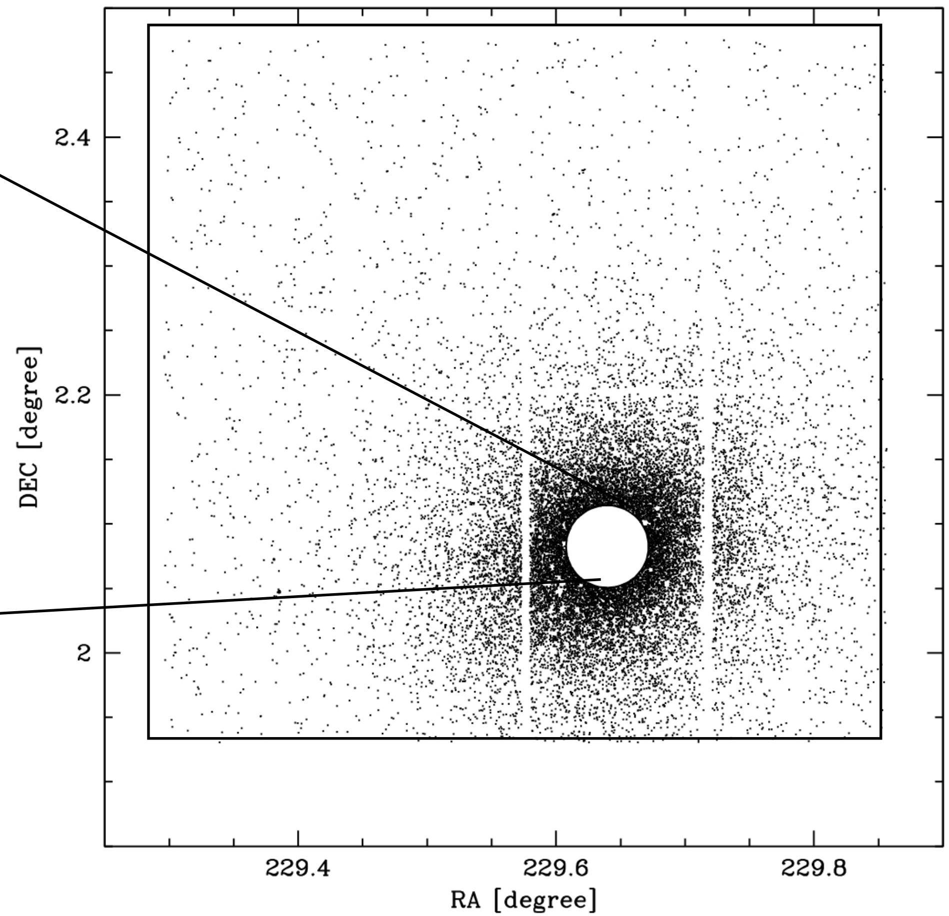
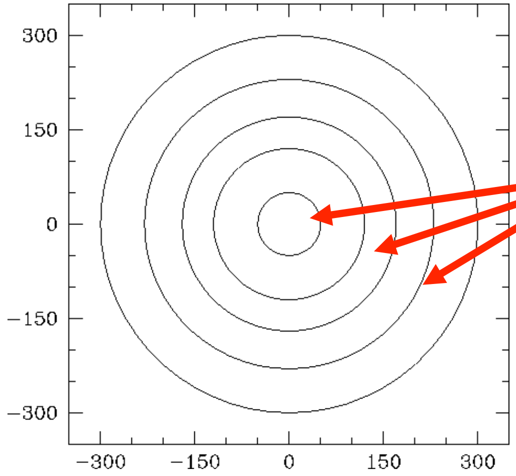


Wide-field ground-based imaging



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**

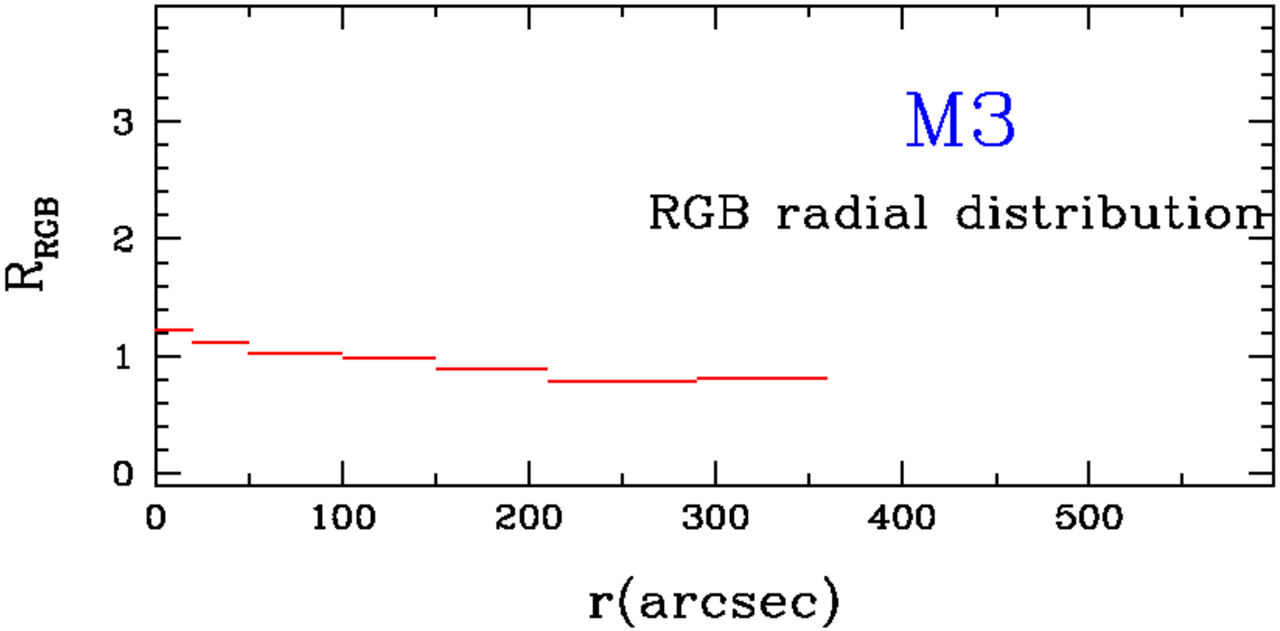
THE BSS RADIAL DISTRIBUTION



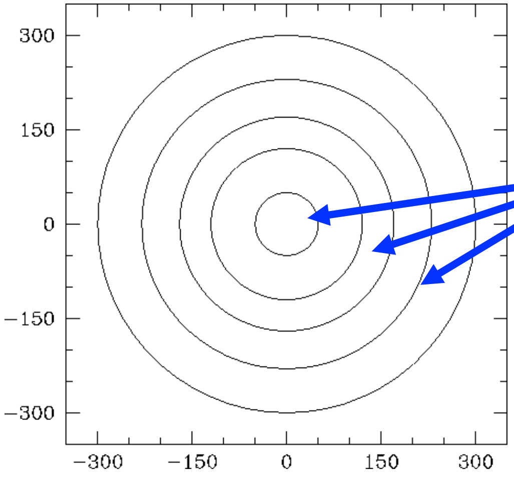
$$R_{RGB} = \frac{N_{RGB}/N_{RGB,TOT}}{L_{samp}/L_{TOT}}$$

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

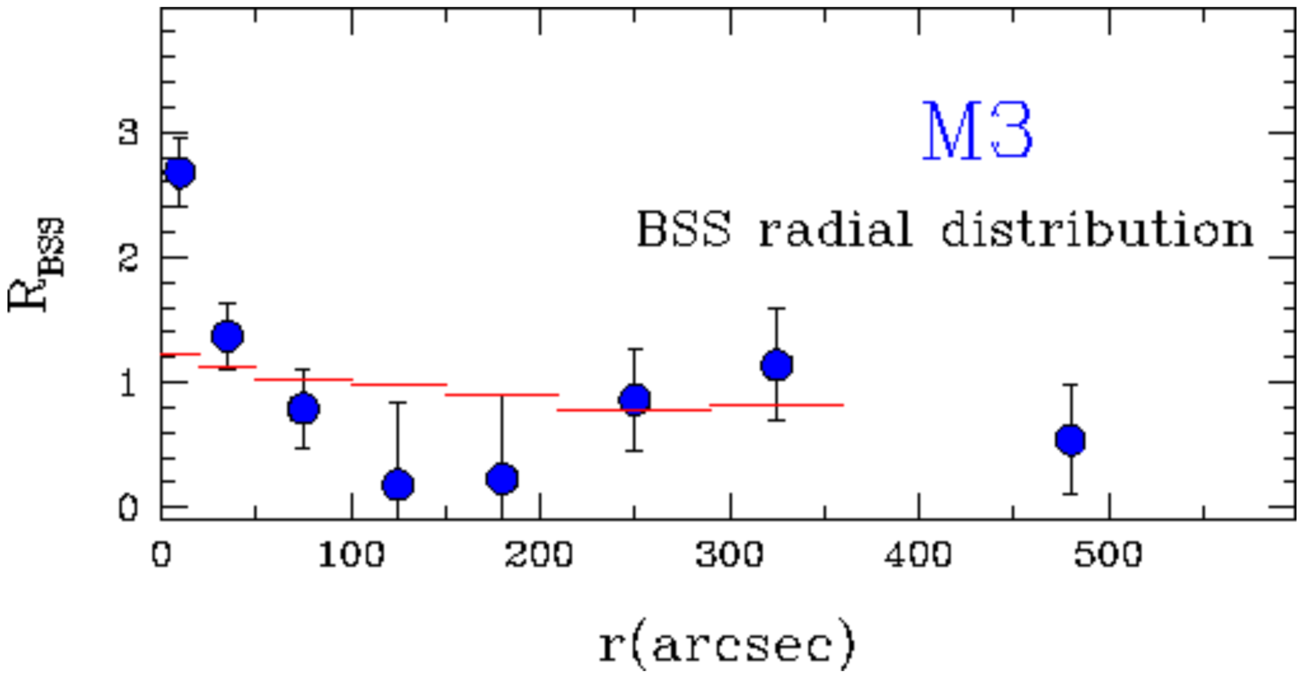
Note that ***a flat distribution*** in this plot means that ***"the number of stars in each annulus exactly scales with the cluster light sampled by each annulus"***



THE BSS RADIAL DISTRIBUTION



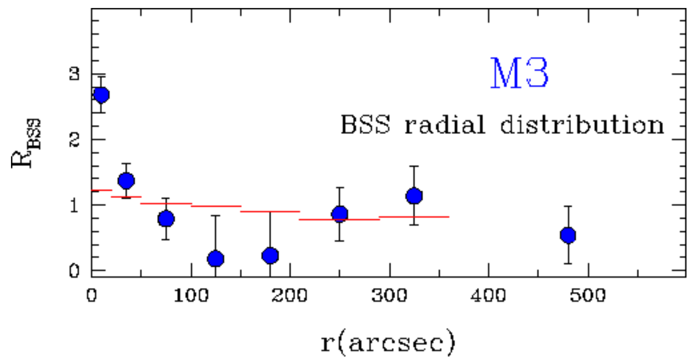
$$R_{BSS} = \frac{N_{BSS}/N_{BSS,TOT}}{L_{samp}/L_{TOT}}$$



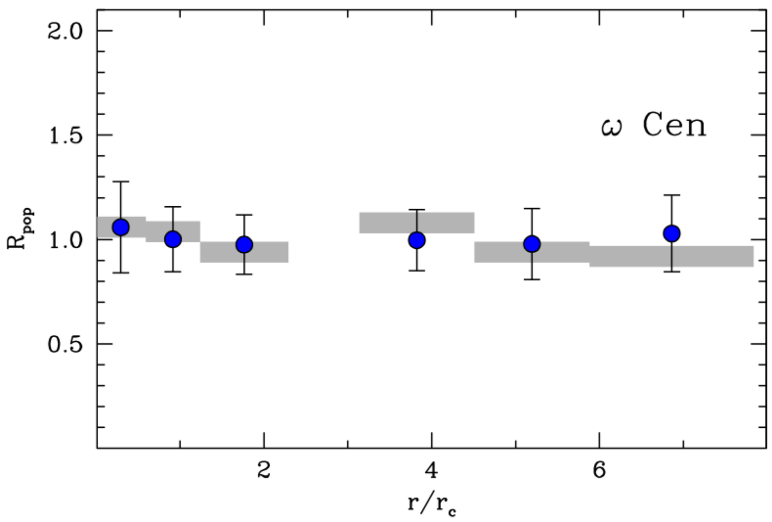
BSS radial distribution

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

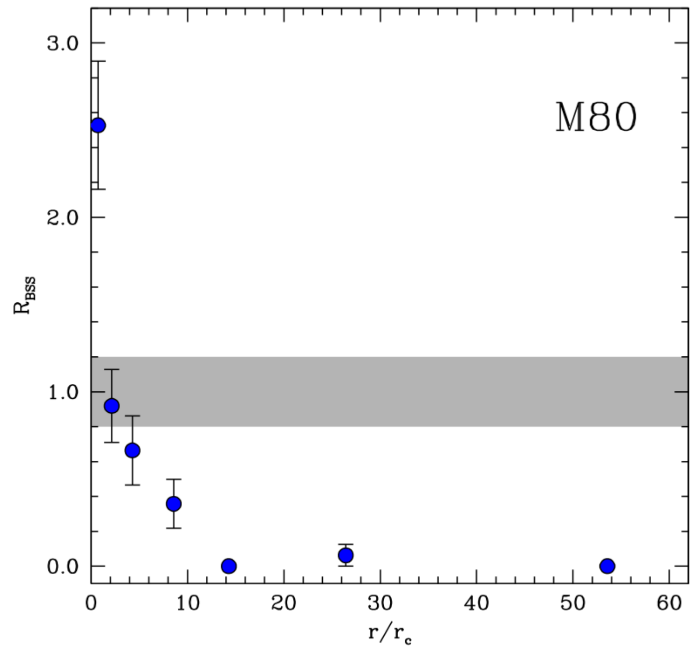
“bimodal”



“Flat”



“Unimodal” (single-peak)



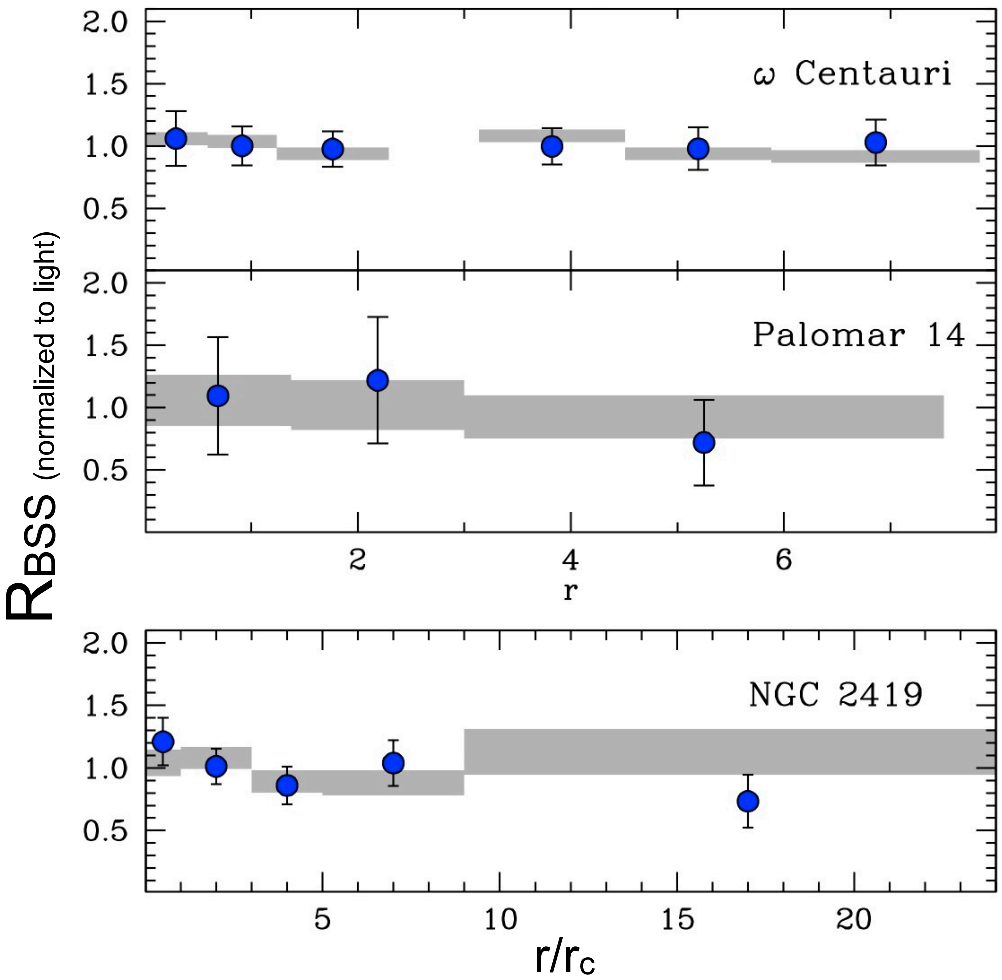
THE DYNAMICAL CLOCK

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: the dynamically YOUNG clusters



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

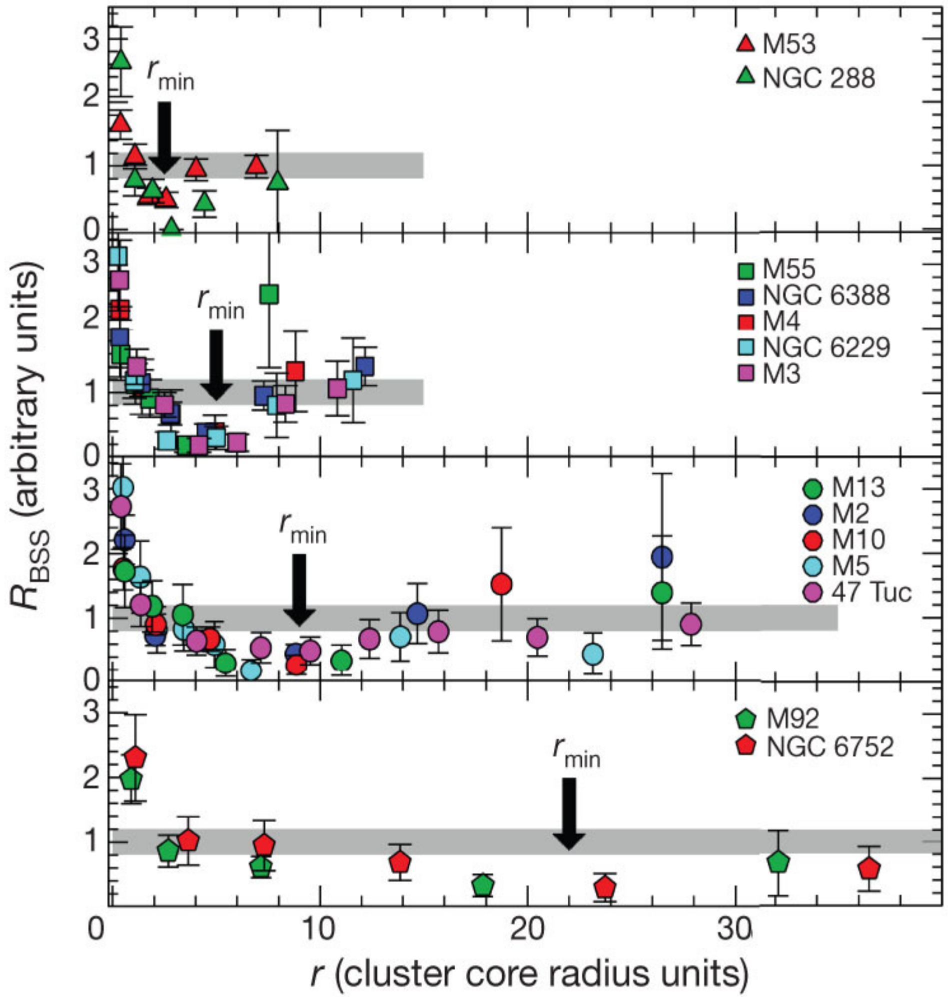
dynamical friction has not affected the BSS distribution yet, not EVEN in the cluster center

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

The dynamical clock

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

Family II: the dynamically INTERMEDIATE-age clusters



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

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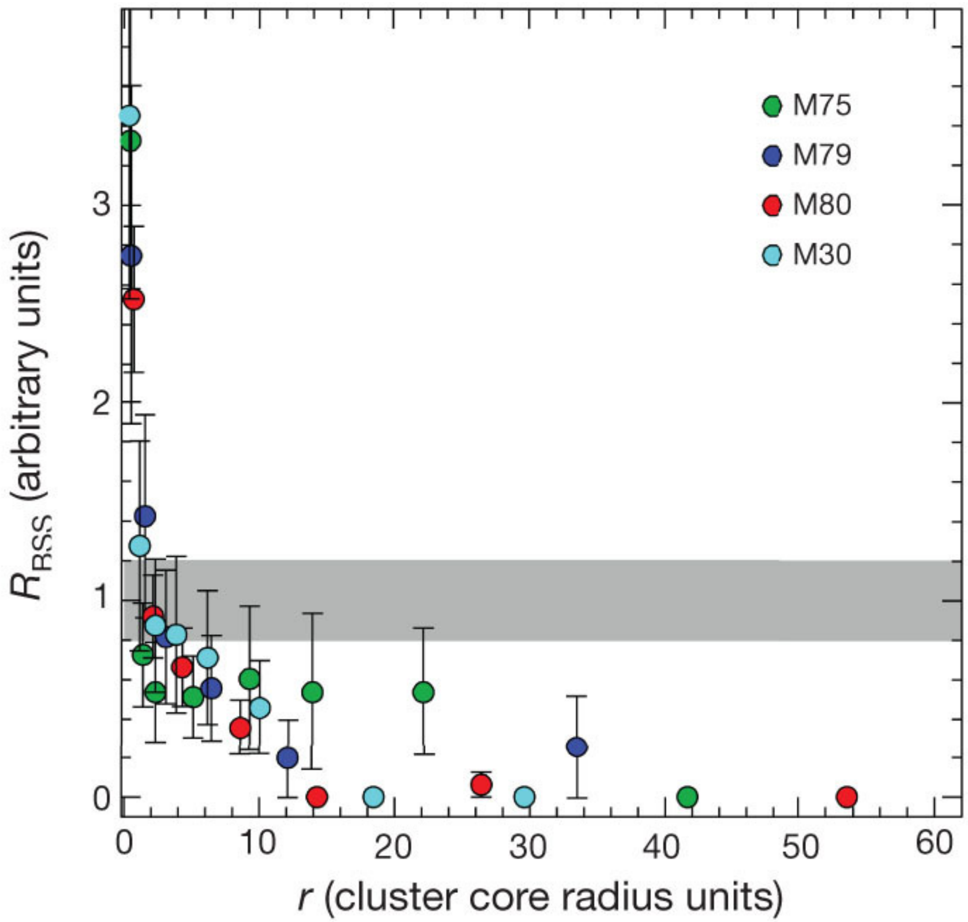
The dynamical clock

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

Family III: the dynamically OLD clusters



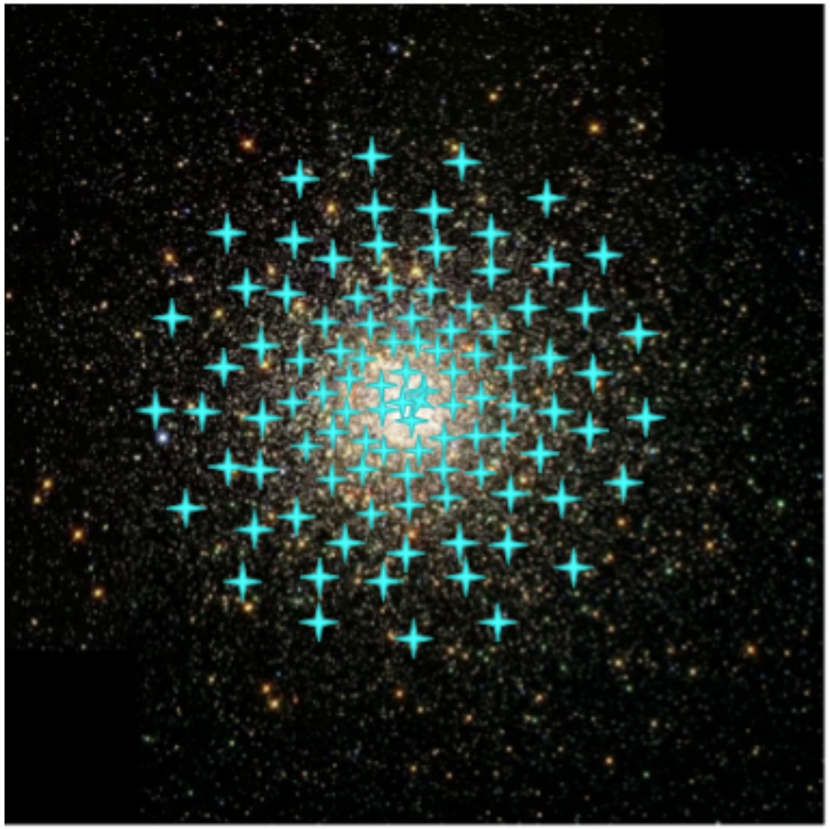
The BSS distribution is **unimodal** with a well defined peak at the cluster center but not rising branch

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

The dynamical clock

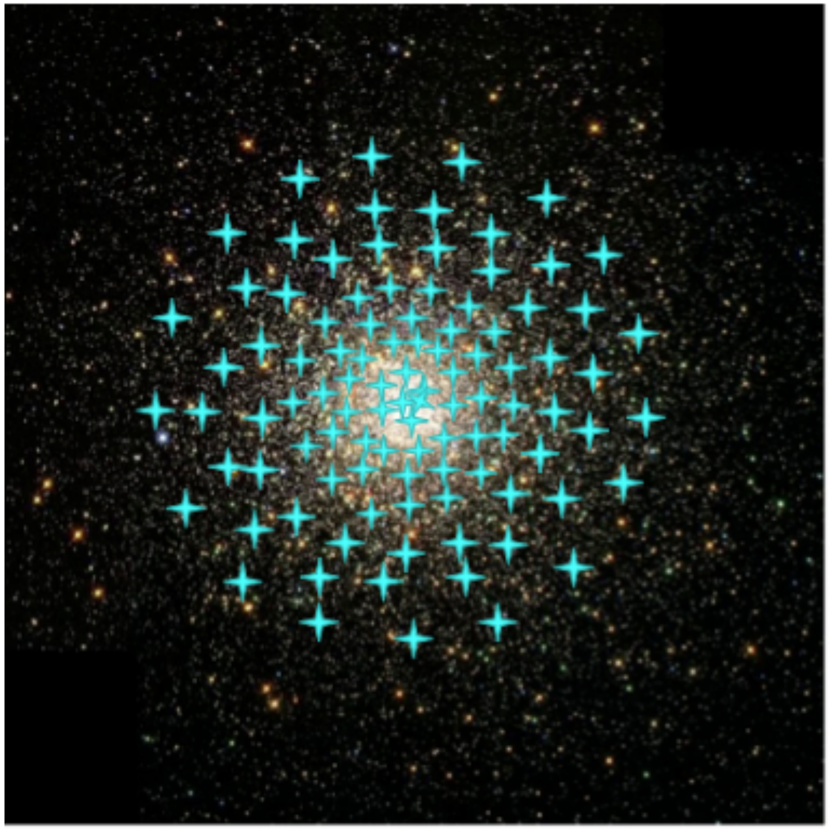
Ferraro et al (2012,Nature,492,393)



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 cluster age.

The dynamical clock

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



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The dynamical clock

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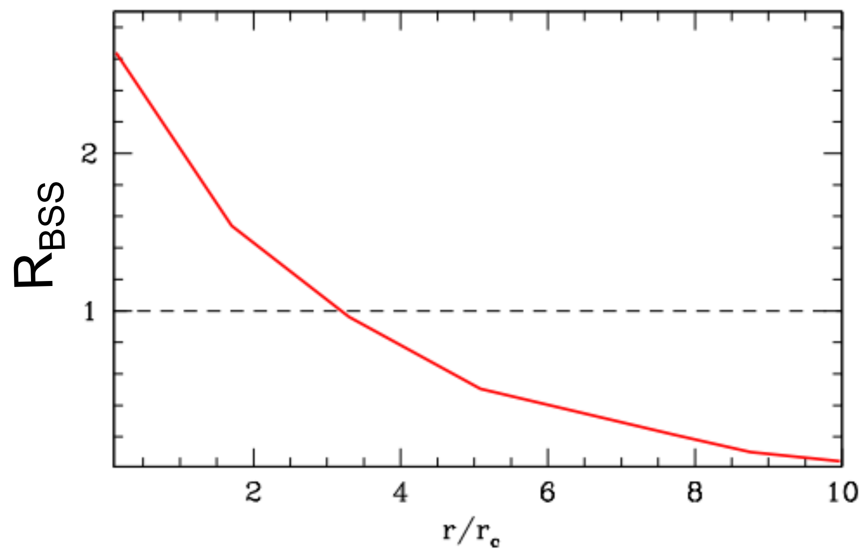
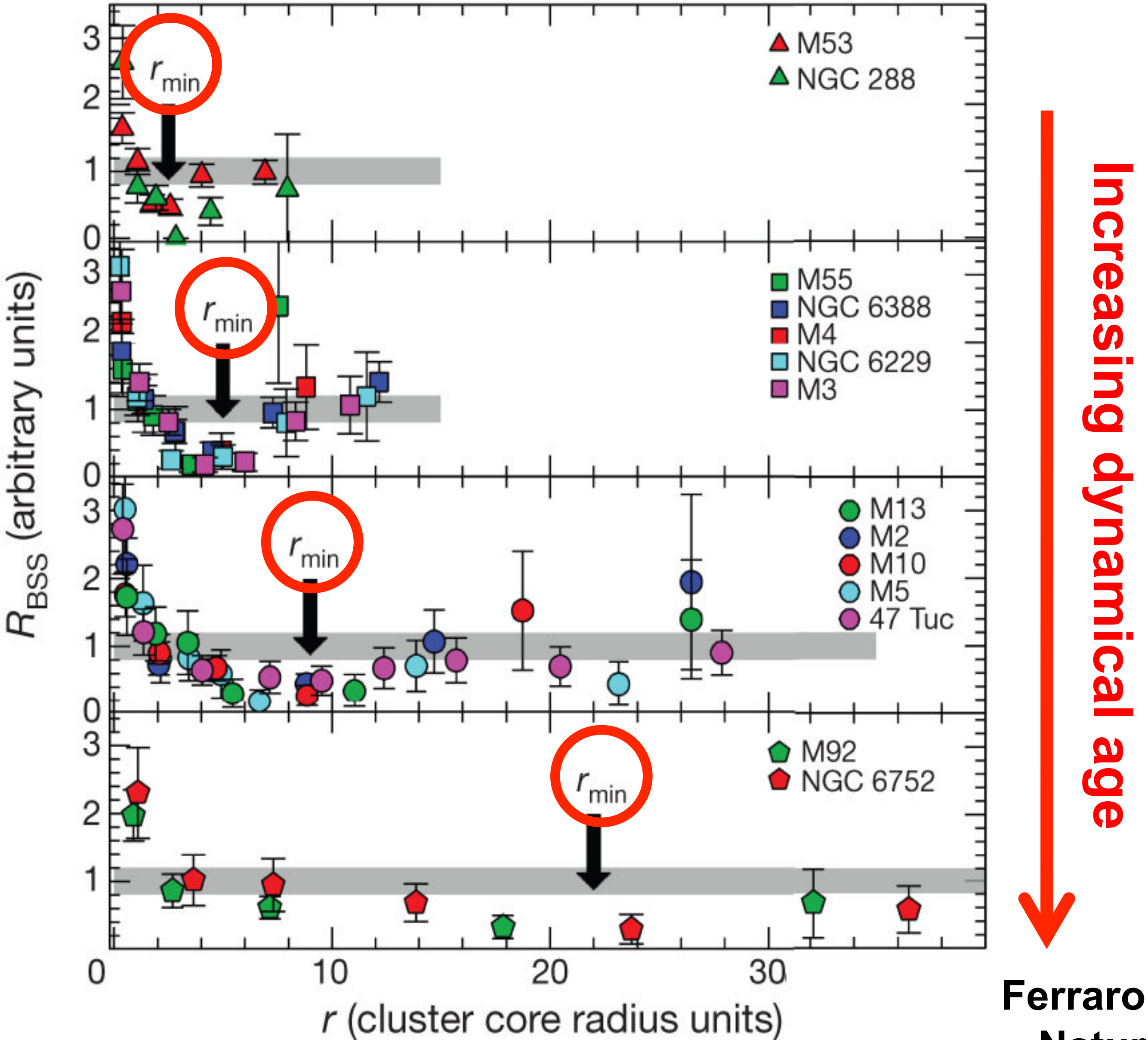


As the engine of a chronometer advances a clock-hand to measure the flow of time, In a similar way dynamical friction moves the minimum outward measuring the dynamical age of a stellar system

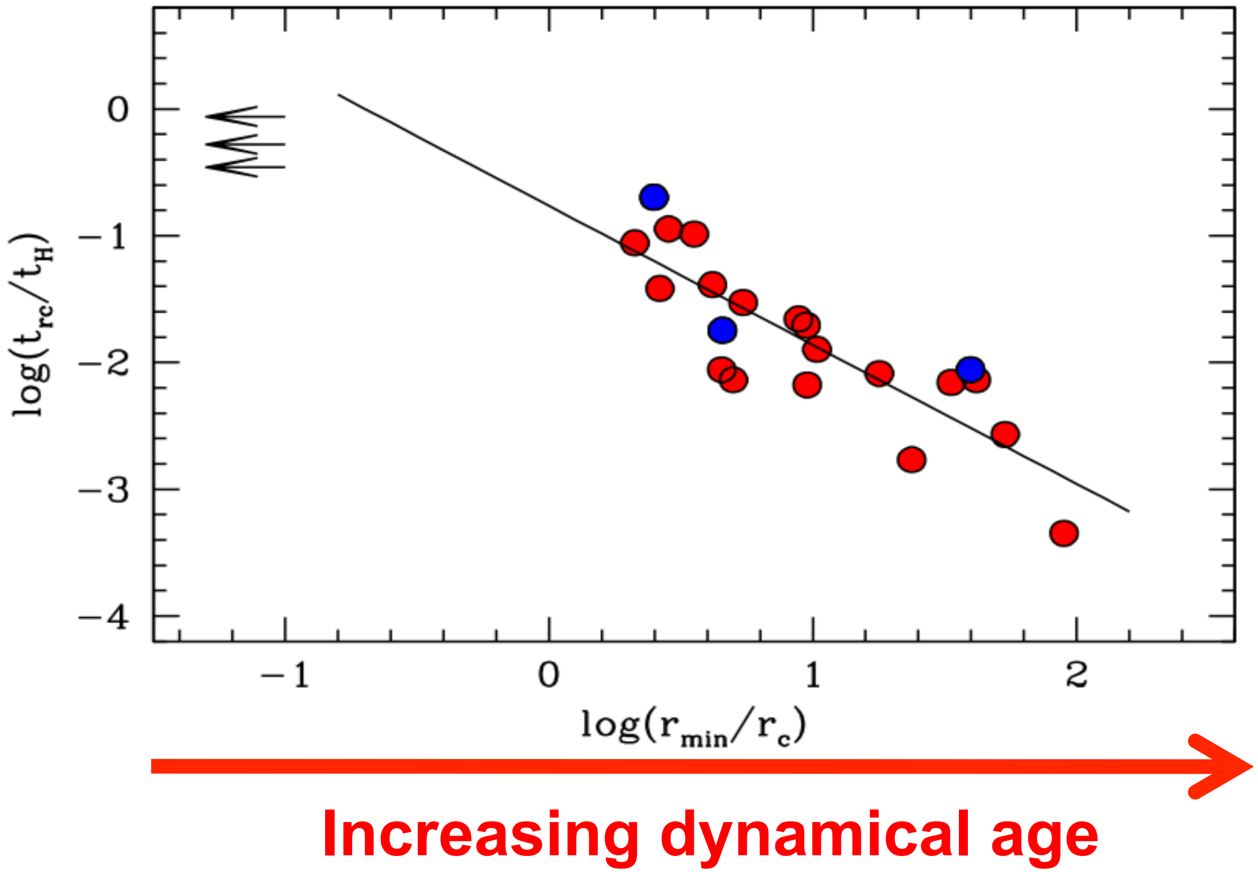


Ferraro et al 2012, Nature,492,393

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})



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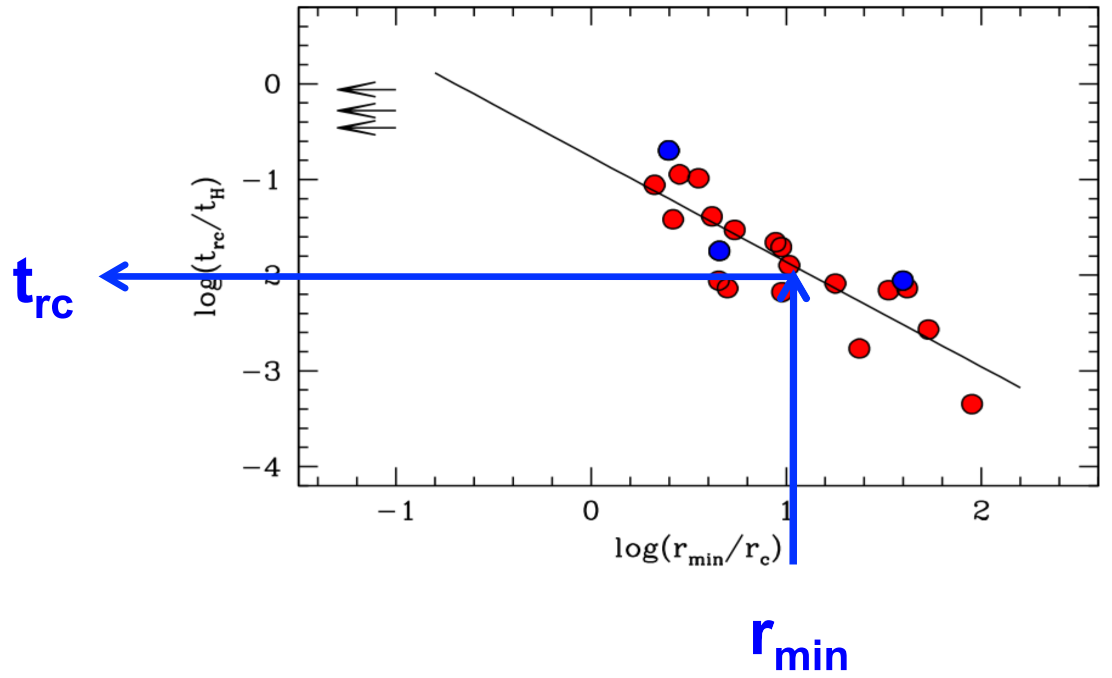
The dynamical clock

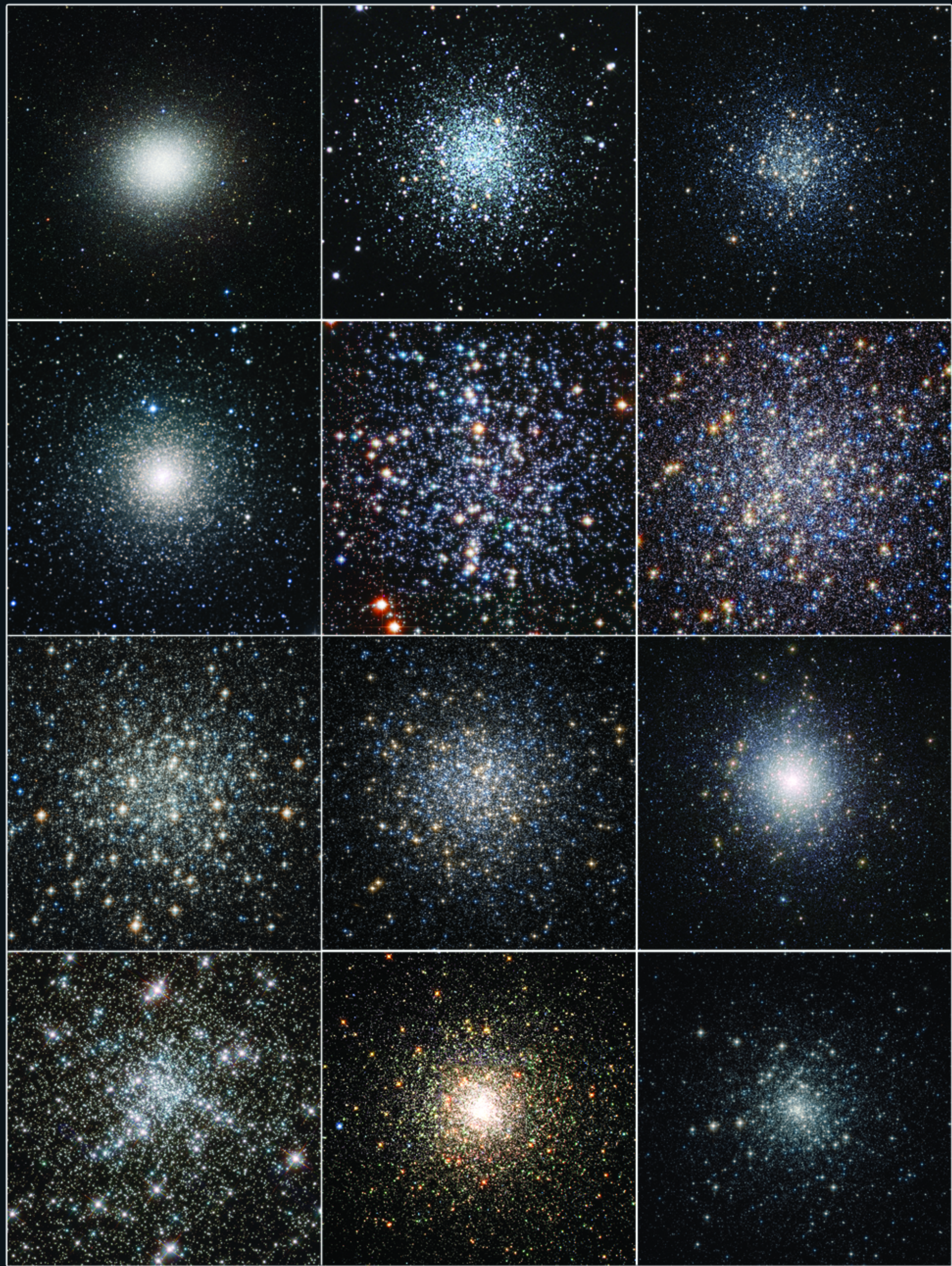
Ferraro et al (2012,Nature,492,393)

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



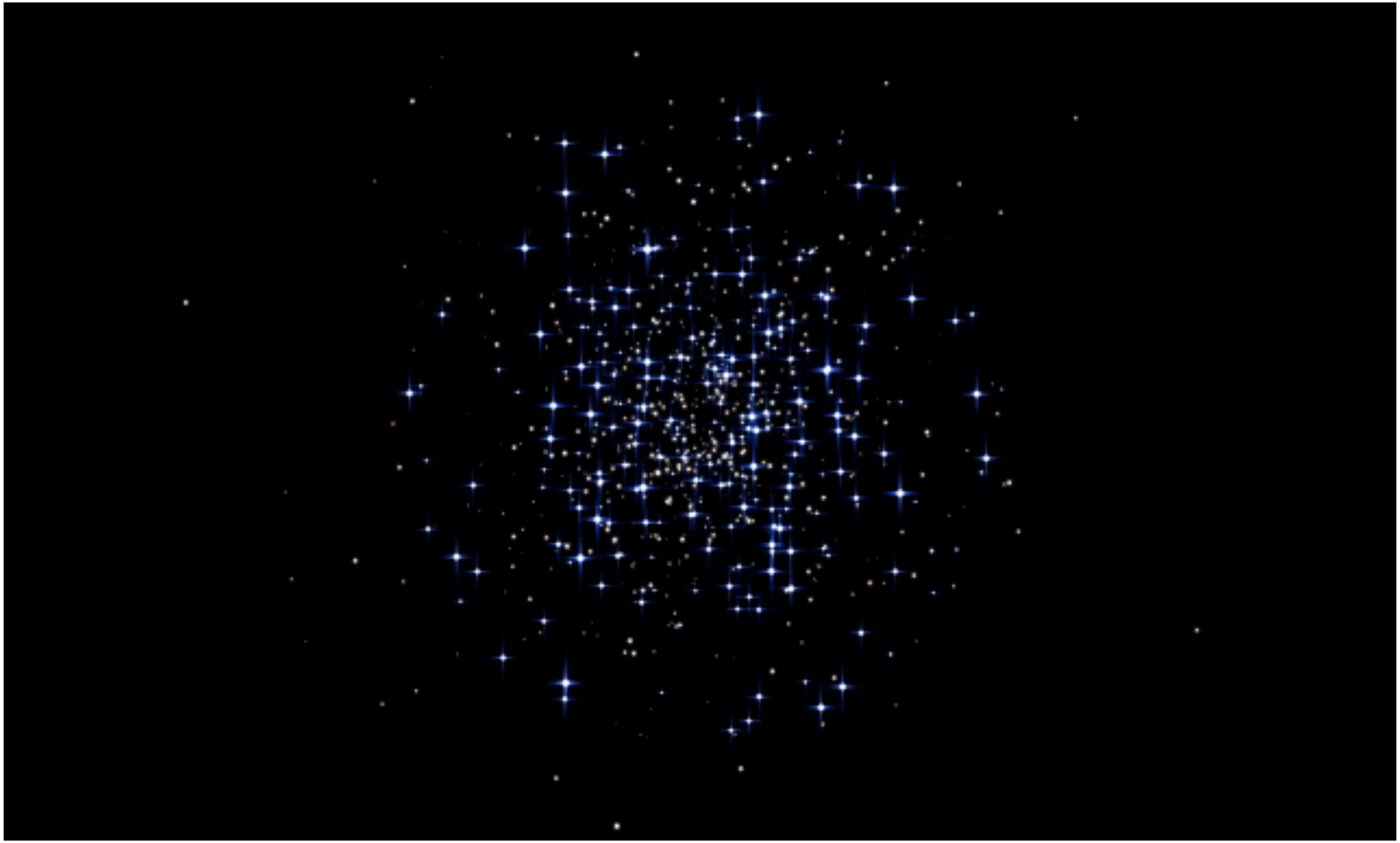
This tool is much more powerful than any previous theoretical estimator of the dynamical time-scale (e.g. the relaxation time-scale at the cluster center) since it simultaneously probe all distances from the cluster center

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).



Thank you for your attention !!!

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

The End