An empirical clock to measure the dynamical age of stellar systems

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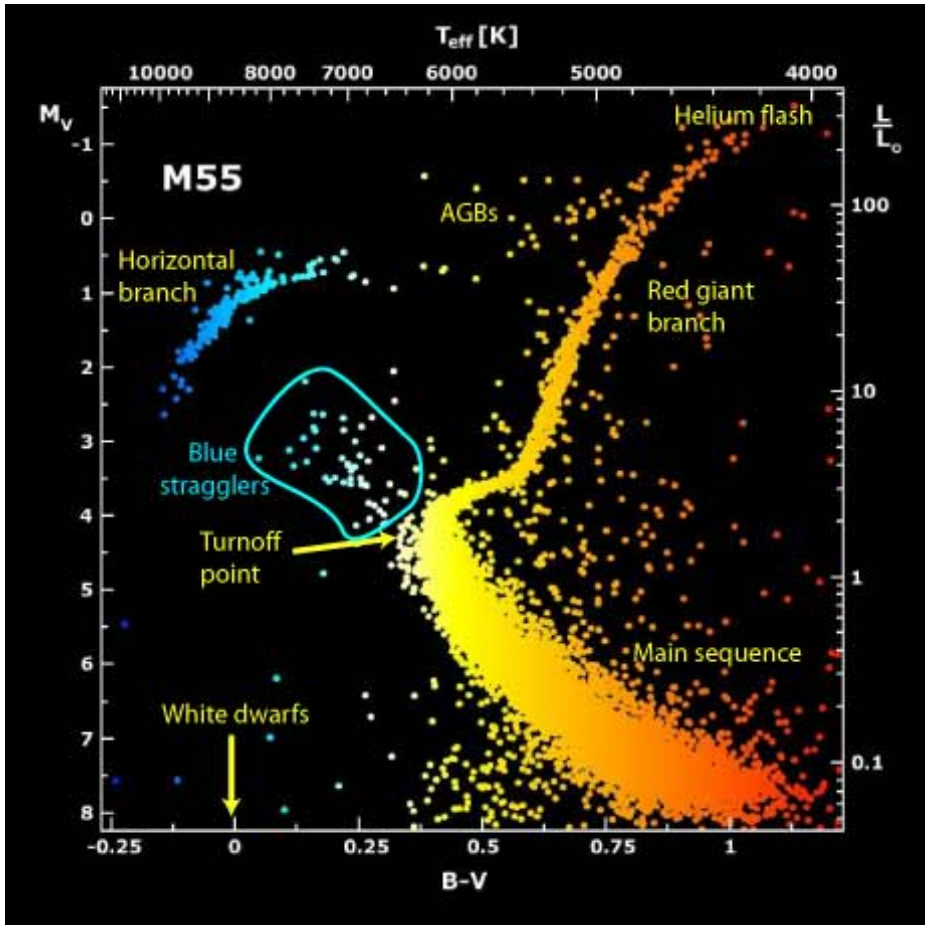
Cosmic-Lab

- 5-year project
- funded by the European Research Council (ERC)
- PI: Francesco R. Ferraro (Dip. of Physics & Astronomy – Bologna Univ.)
- 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

What are Blue Straggler Stars?



- BSS were discovered for the first time by Sandage (1953) in M3

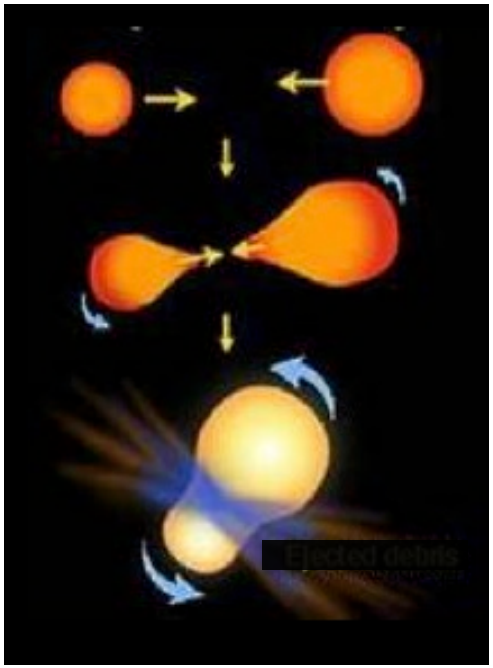
- They are a common population of all stellar systems (Mathieu & Geller 2009; Monelli et al. 2011)

- They are brighter and bluer (hotter) than TO stars thus mimicking a younger stellar population

Direct measures have shown that BSS are up to 2 times more massive than TO stars (Shara et al. 1996; Gilliland et al. 1998; De Marco et al. 2004)

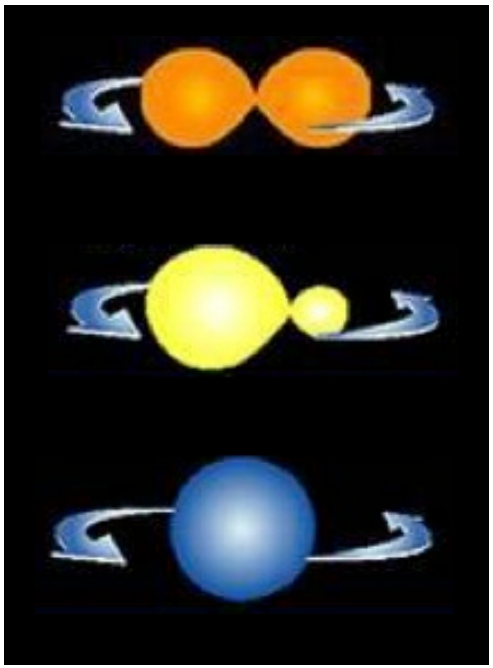
The BSS formation mechanisms

COLLISIONAL BSS



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

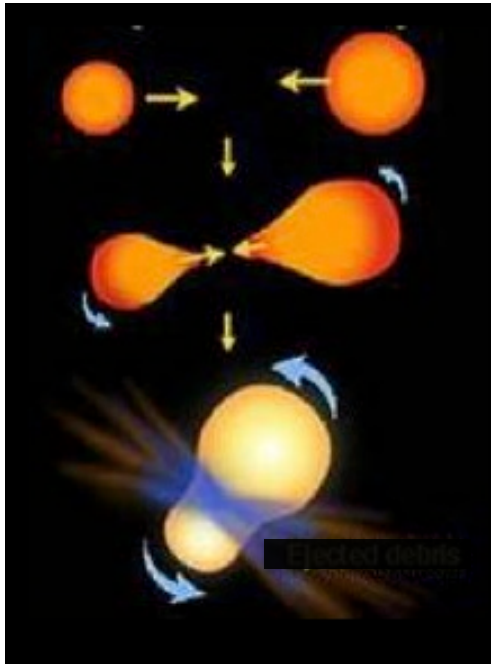
MASS-TRANSFER BSS



depend on shrinking of binaries
due to **dynamical interactions**
and stellar evolution (McCrea 1964)

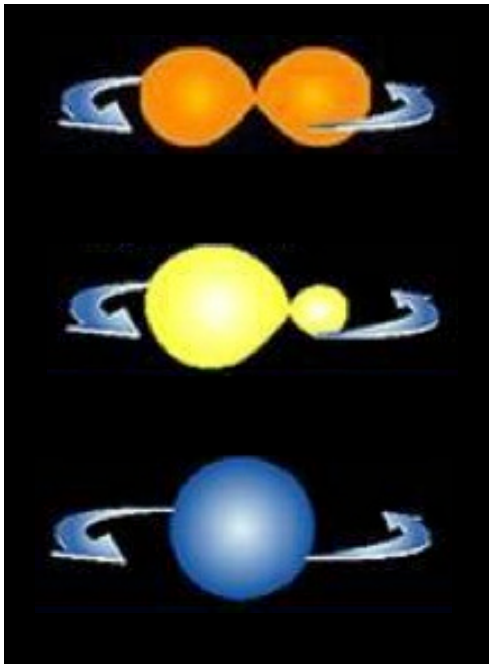
Blue Straggler Stars as dynamical probe

COLLISIONAL BSS



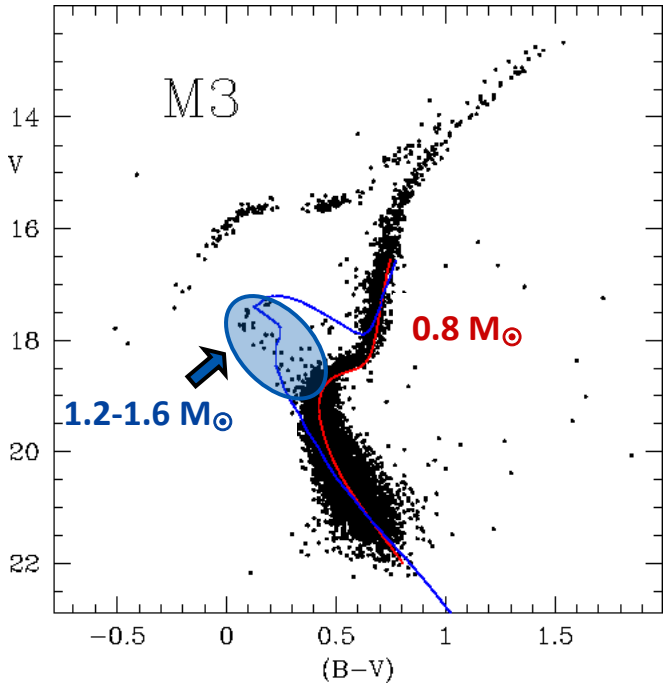
collisions

MASS-TRANSFER BSS



dynamical interactions

MORE MASSIVE THAN THE AVERAGE



dynamical friction

BSS: crucial probes of stellar dynamics

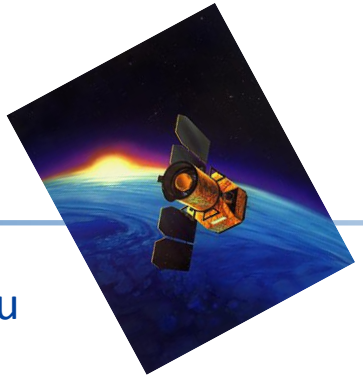
The BSS RADIAL DISTRIBUTION: the general approach

✓ **central regions** (high-density): **high-resolution (UV + optical)**

HST (WFPC2, ACS, WFC3)

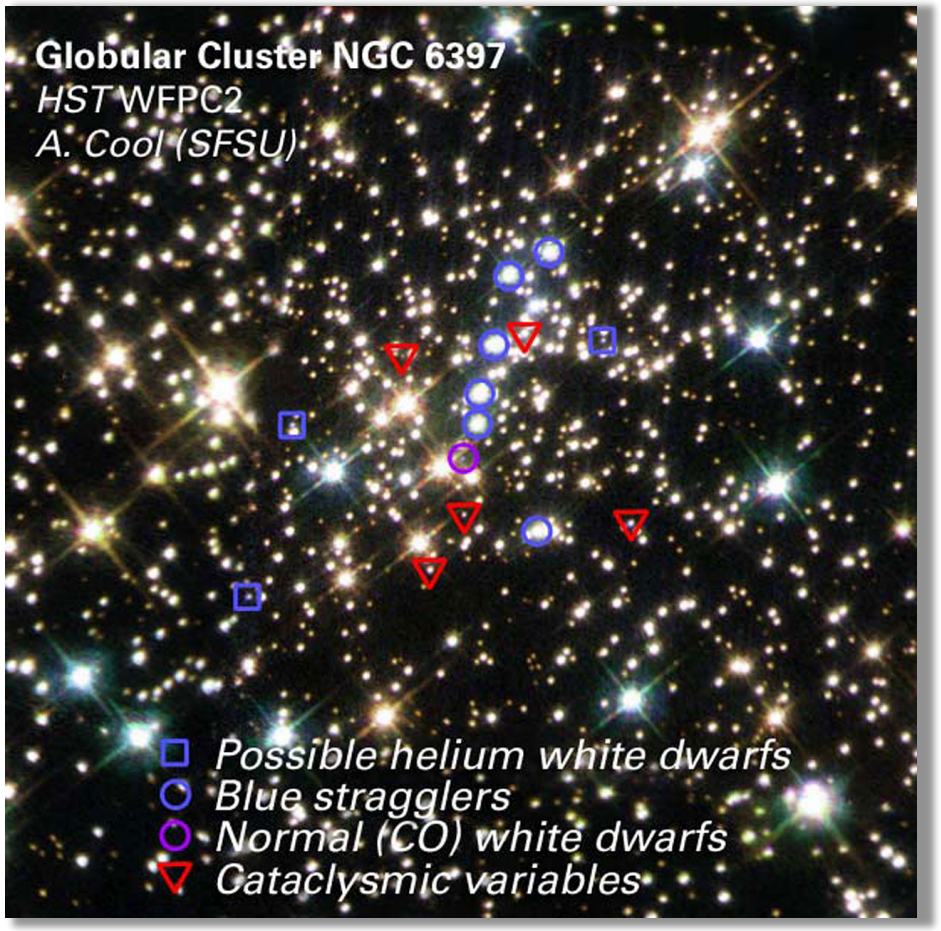
✓ **external regions** (large extension): **wide-field capabilities**

- **optical: ground-based** (ESO-WFI, Megacam)
- **UV: GALEX**

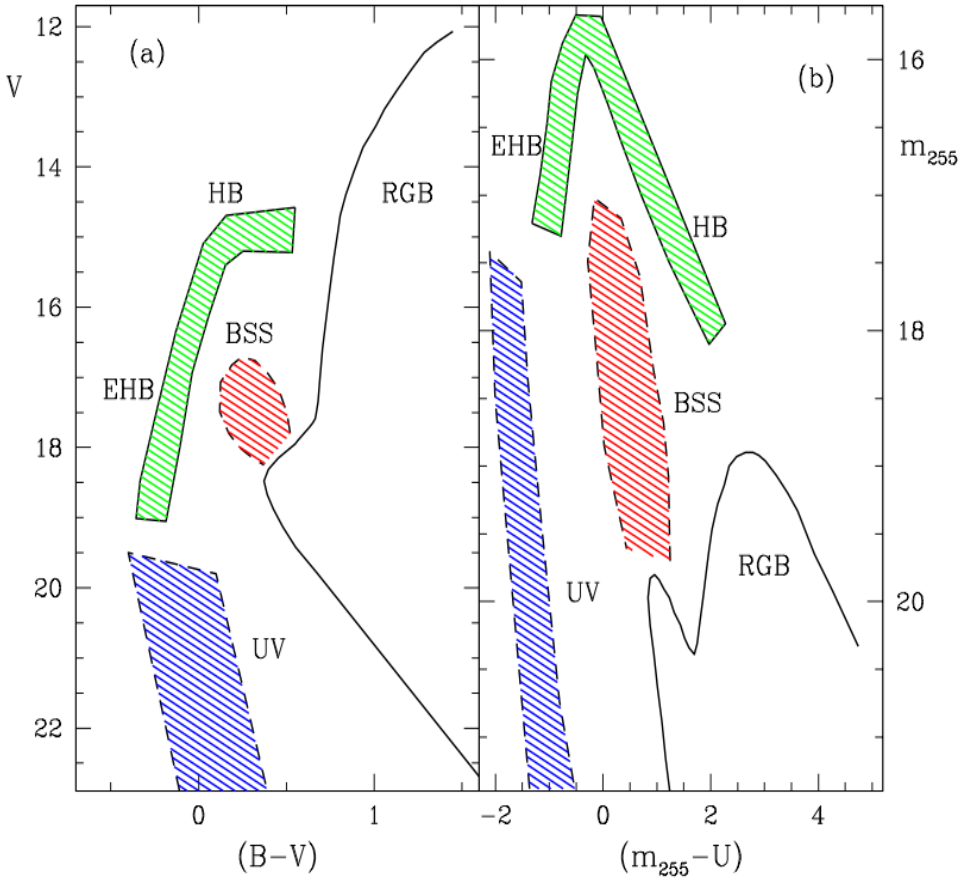


WHY UV?

NO CROWDING



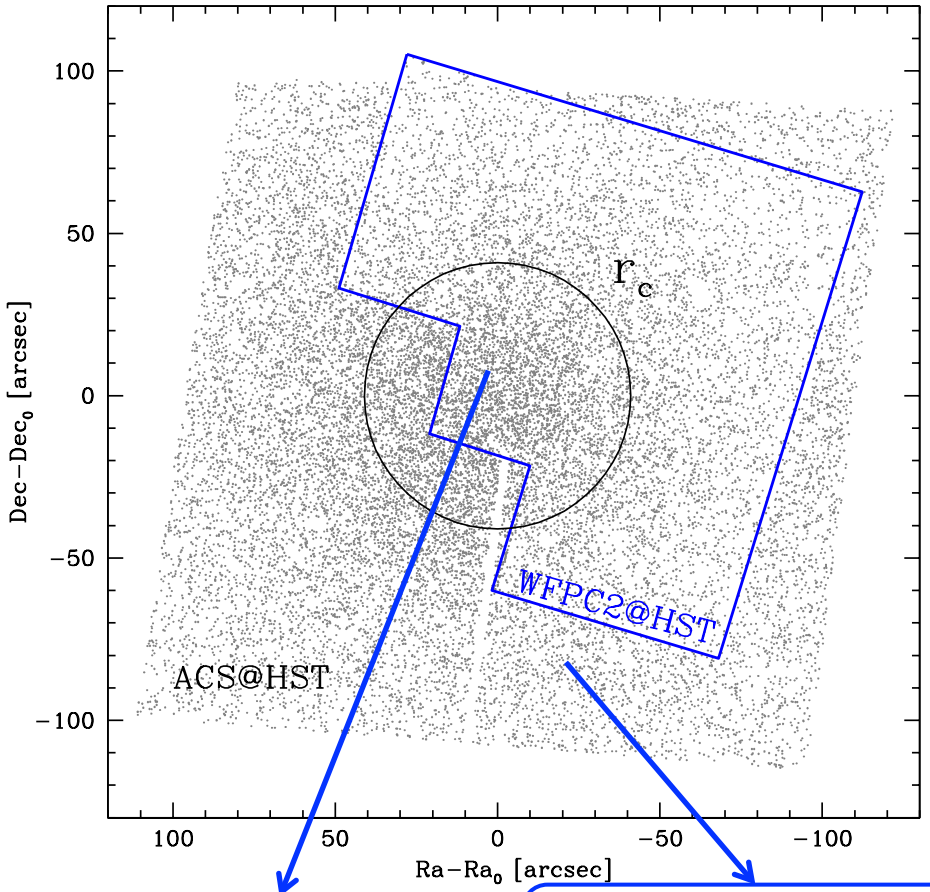
BSS ARE BRIGHTER



A typical case: NGC6254 (M10)

Dalessandro et al. 2013

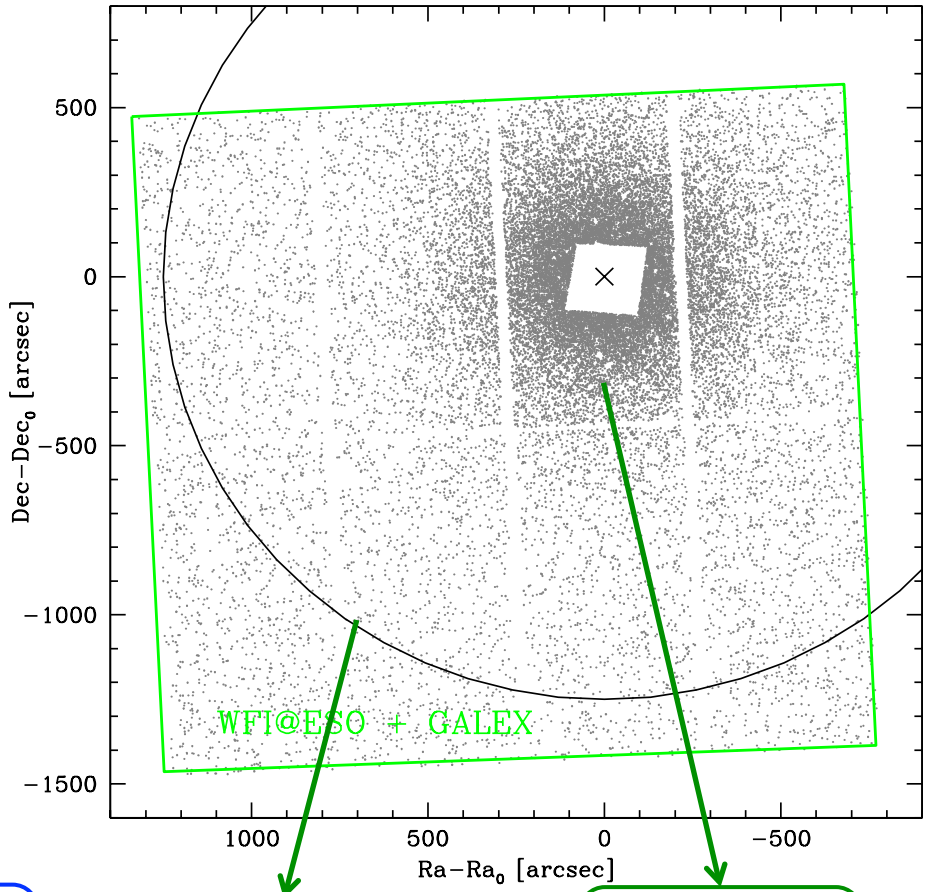
High-Res: HST/WFPC2+ACS



WFPC2@HST:
F255W, F336W, F555W

ACS@HST:
F606W, F814W

Low-Res:WFI@ESO + GALEX

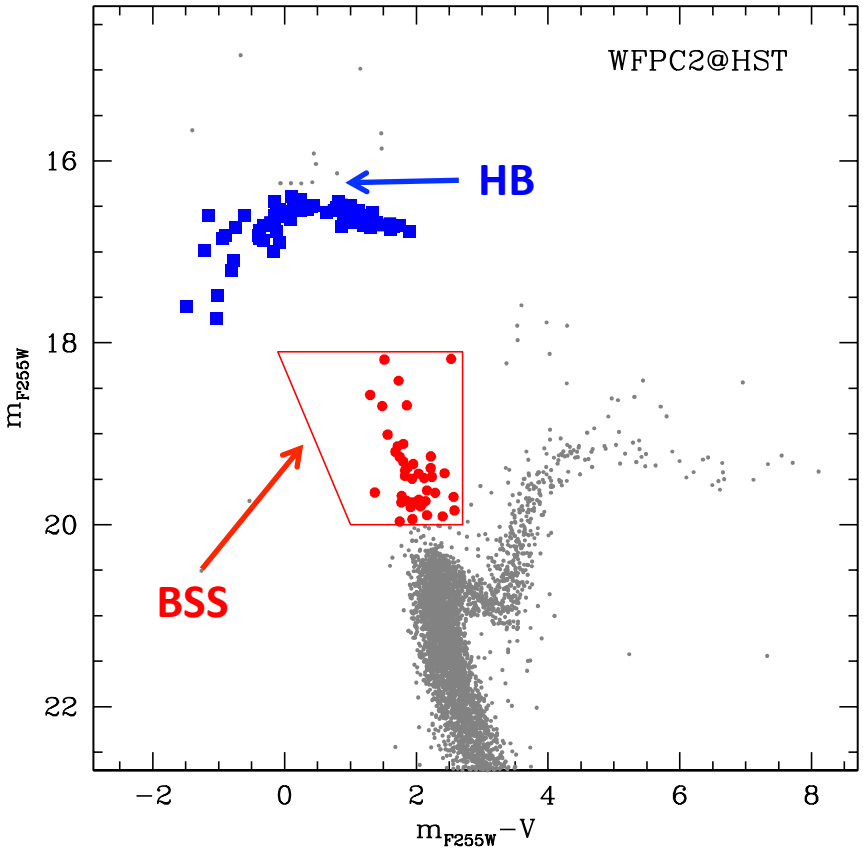


GALEX:
FUV, NUV

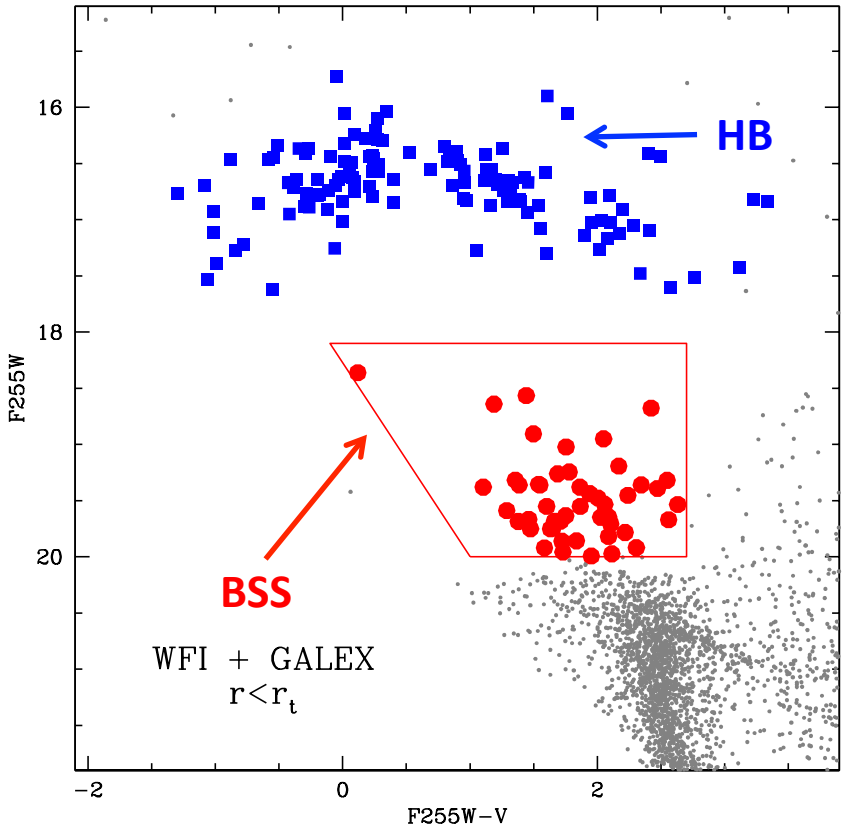
WFI@ESO:
V, I

BSS and reference population selections

High-Res: HST/WFPC2+ACS

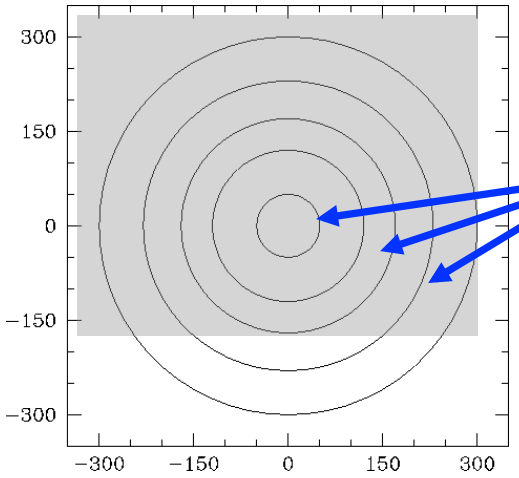


Low-Res:WFI@ESO + GALEX



Dalessandro et al. 2013

The double normalized ratio



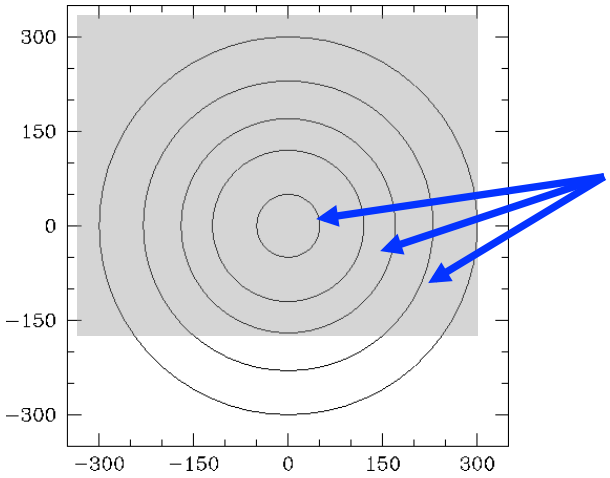
$$R_{POP} = \frac{N_{POP}/N_{POP,TOT}}{L_{samp}/L_{TOT}}$$

$R_{pop}=1$ for any non-segregated population

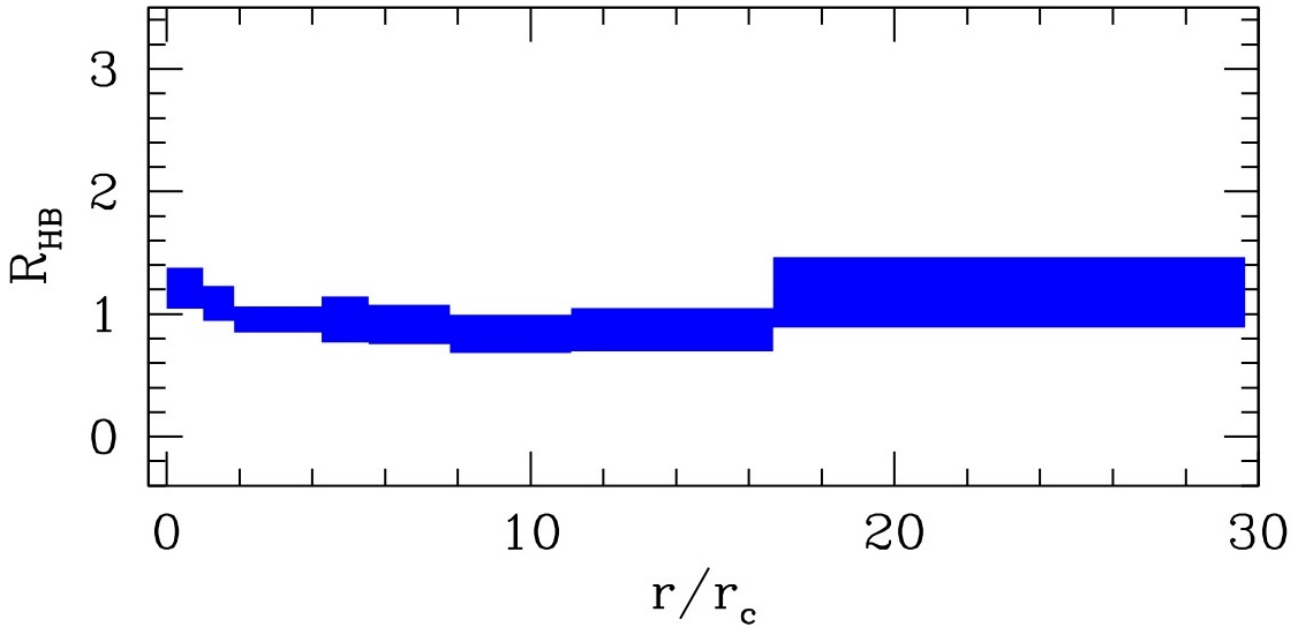
from *The Consumption Theorem*

Renzini & Buzzoni 1986; Renzini & Fusi Pecci 1988

The double normalized ratio



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



HB stars show a FLAT radial distribution

The double normalized ratio: what we should expect for BSS?

dynamical friction →
- makes BSS sinking towards the **centre**
- progressively affects BSS **at larger and larger distances**

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

M_{BSS} = 1.2 Msol

$\rho(r)$, $\sigma(r)$

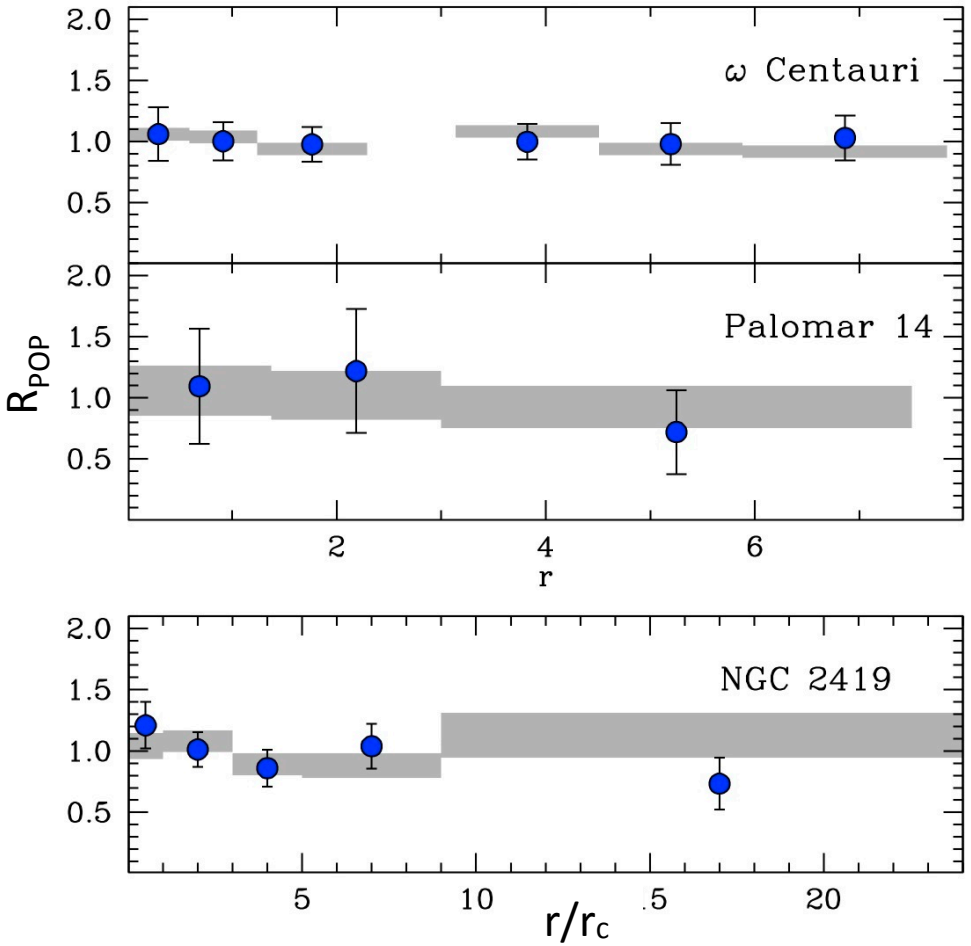
BSS at all radial distances

provide information on dynamical processes

A FIRST CLASSIFICATION

Ferraro et al. 2012

Family I: dynamically young stellar systems

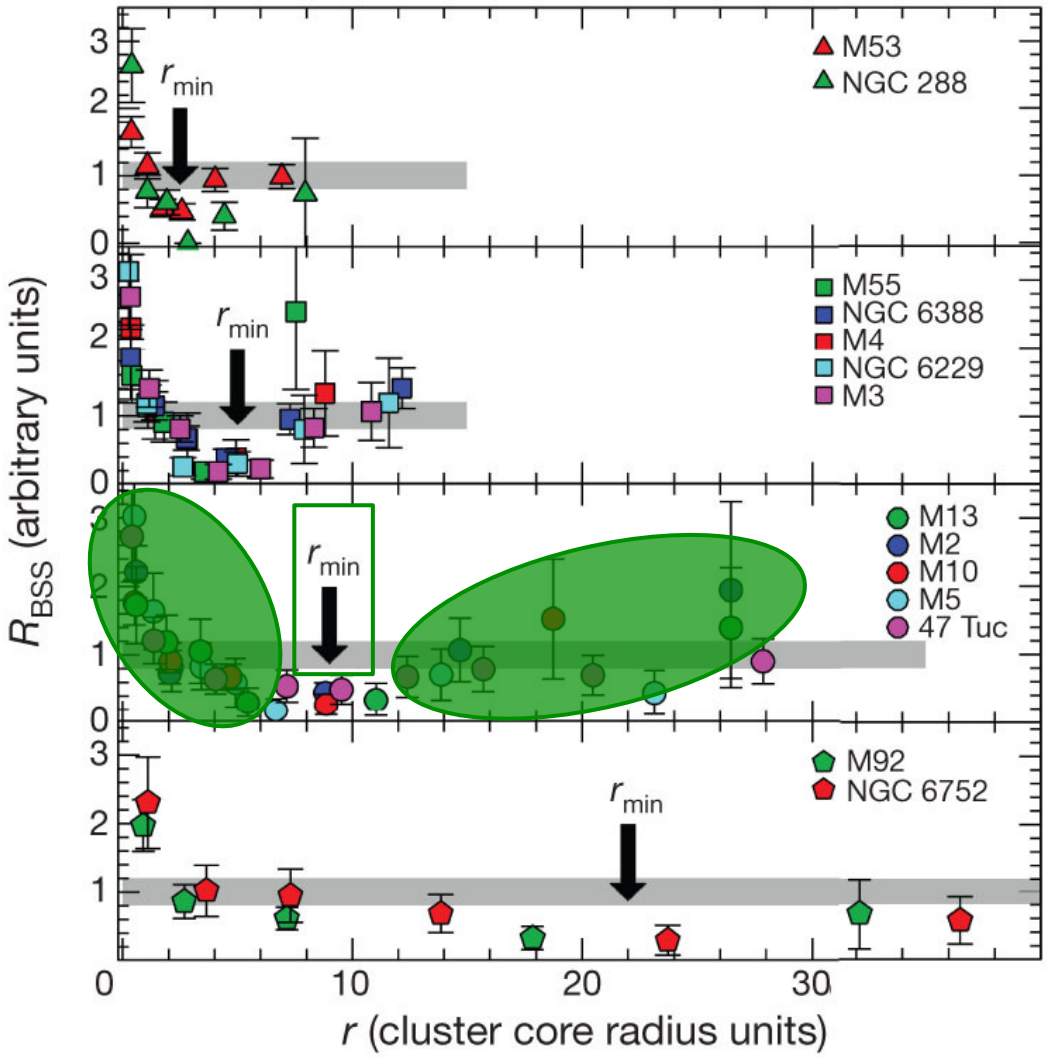


ωCen, Pal14, NGC2419 are not mass-segregated yet (even in the central regions)

ωCen: $t_{rc} \sim t_{AGE}$
Pal14: t_{rc} ~20 Gyr
NGC2419: t_{rc} ~18Gyr

(Ferraro et al. 2006)
(Beccari et al. 2011)
(Dalessandro et al. 2008)

Family II : intermediate dynamical age



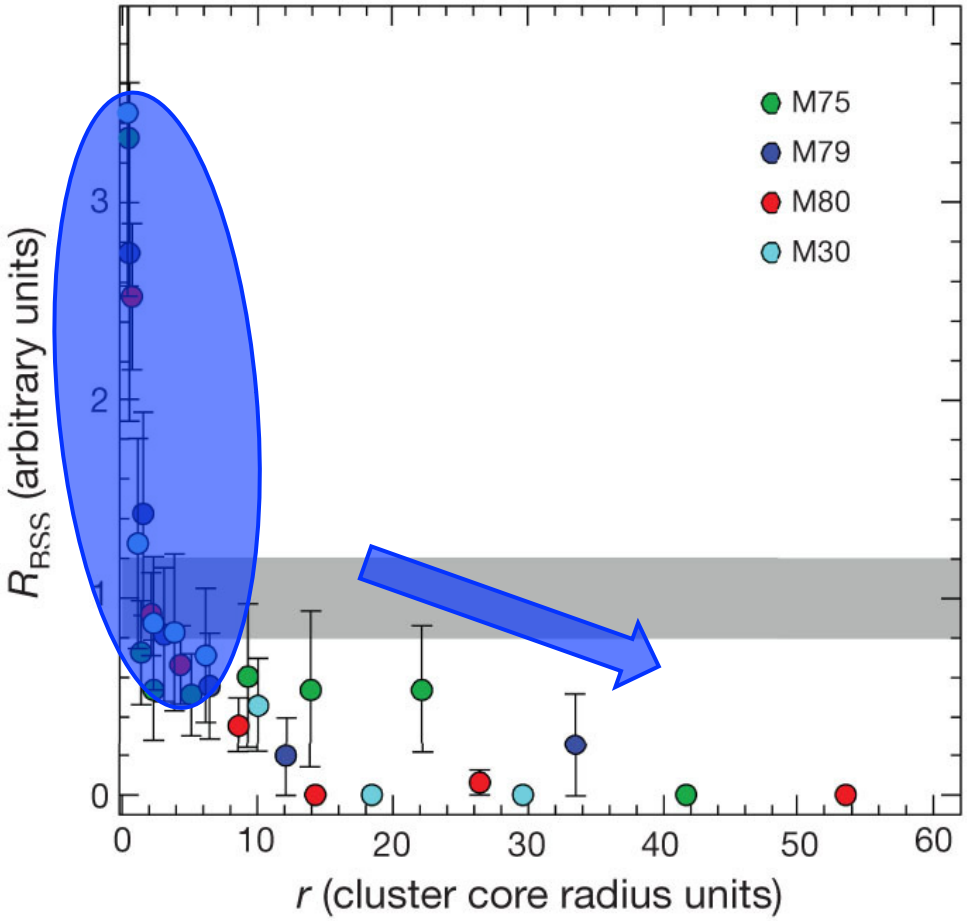
The central peak is due to BSS already sunk to the cluster core because of dynamical friction

r_{min} is the distance at which dynamical friction has been able to work

The external rising branch is composed by unperturbed BSS

Dynamical friction has had time to shape the BSS radial distribution

Family III: dynamically old clusters



A clear central peak

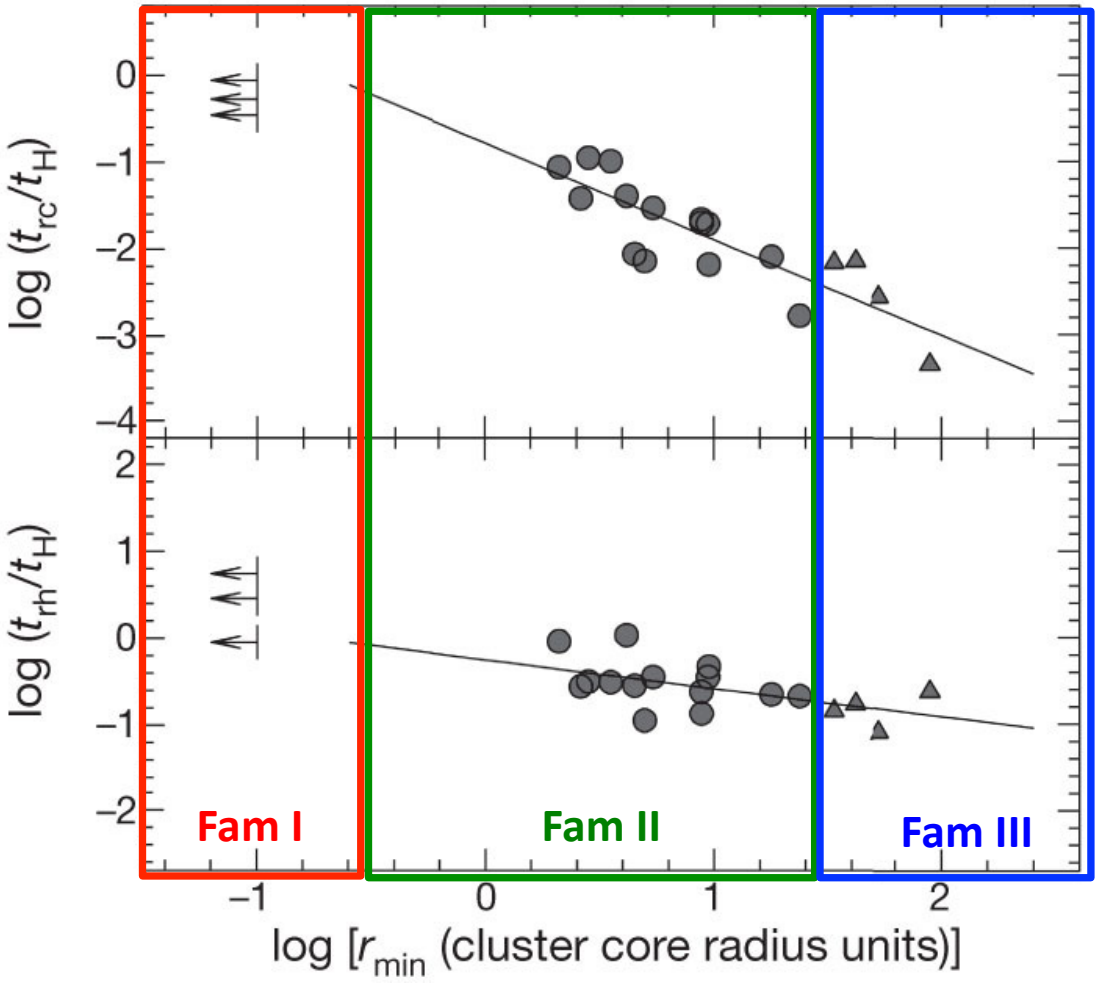
A monotonic decreasing distribution

r_{min} is larger than the cluster extension

All BSS have already sunk to the cluster center because of dynamical friction

THE DYNAMICAL CLOCK

Ferraro et al. 2012



The first calibration:

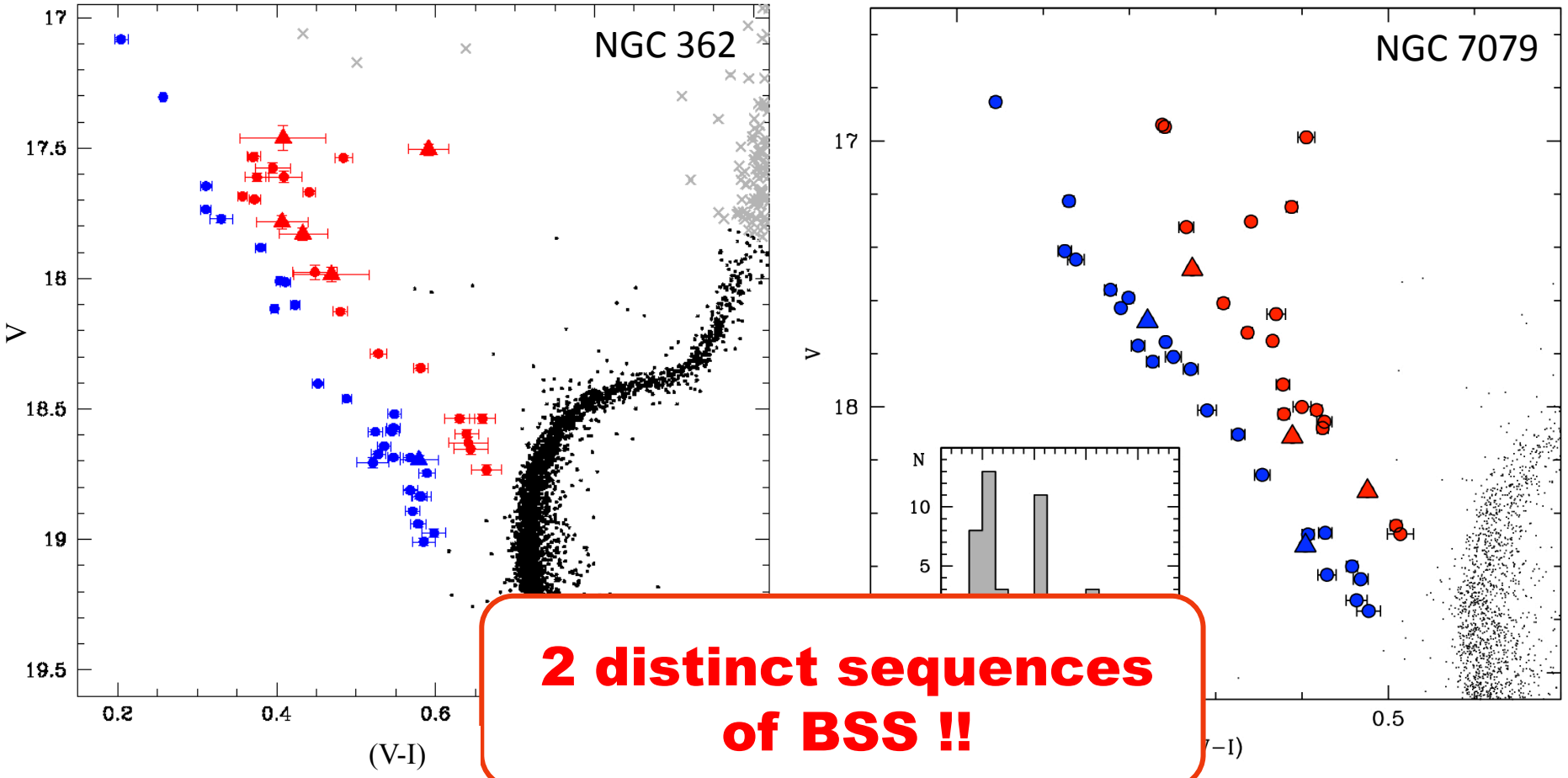
$$\log(t_{rc}/t_H) = -1.11 \log(r_{min}) - 0.78$$

$$\log(t_{rh}/t_H) = -0.33 \log(r_{min}) - 0.25$$

THE FIRST EMPIRICAL CLOCK ABLE TO MEASURE THE DYNAMICAL AGE

DOUBLE BSS SEQUENCES IN PCC CLUSTERS

Dalessandro et al. 2013; Ferraro et al. 2009

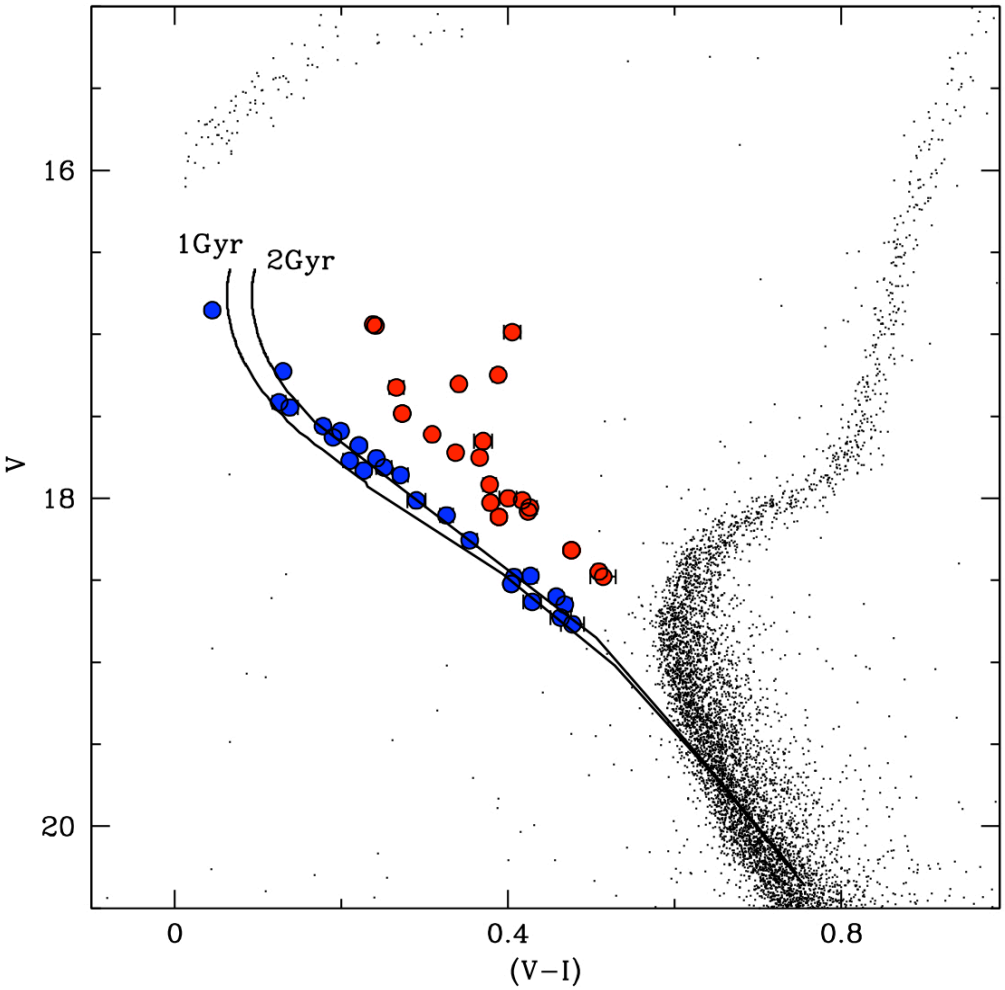


Evolutionary models of COL-BSS (Sills et al. 2009)

- collisions between two MS stars (0.4 - 0.8 $M_{\odot}$)
- $Z = 10^{-4}$ ($Z_{M30} = 2.5\ 10^{-4}$)

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

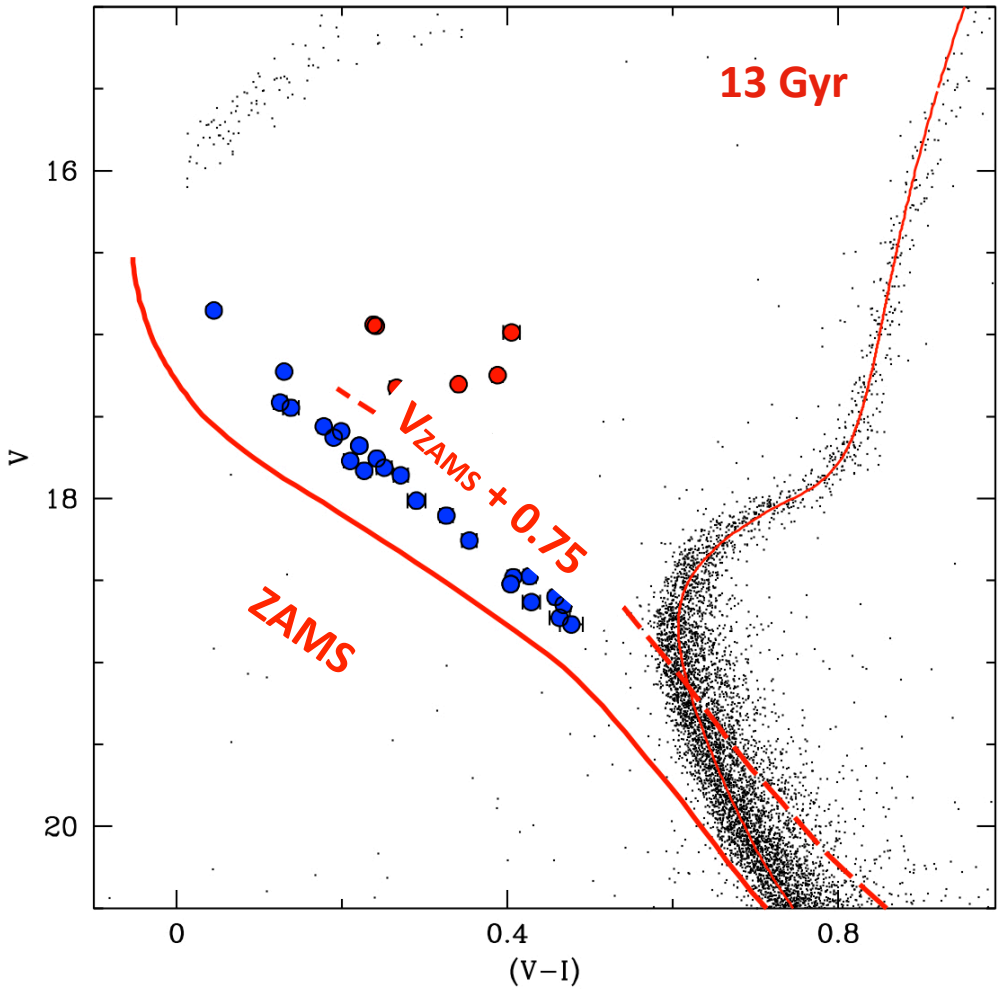
- red-BSS sequence **too red** to be reproduced by collisional isochrones of **any** age



Single star isochrones of Z = 2 10^{-4} (Cariulo et al. 2004):

- 13 Gyr → good fit to CMD
- 0.5 Gyr → ZAMS

red-BSS sequence well reproduced by models of mass-transfer binaries



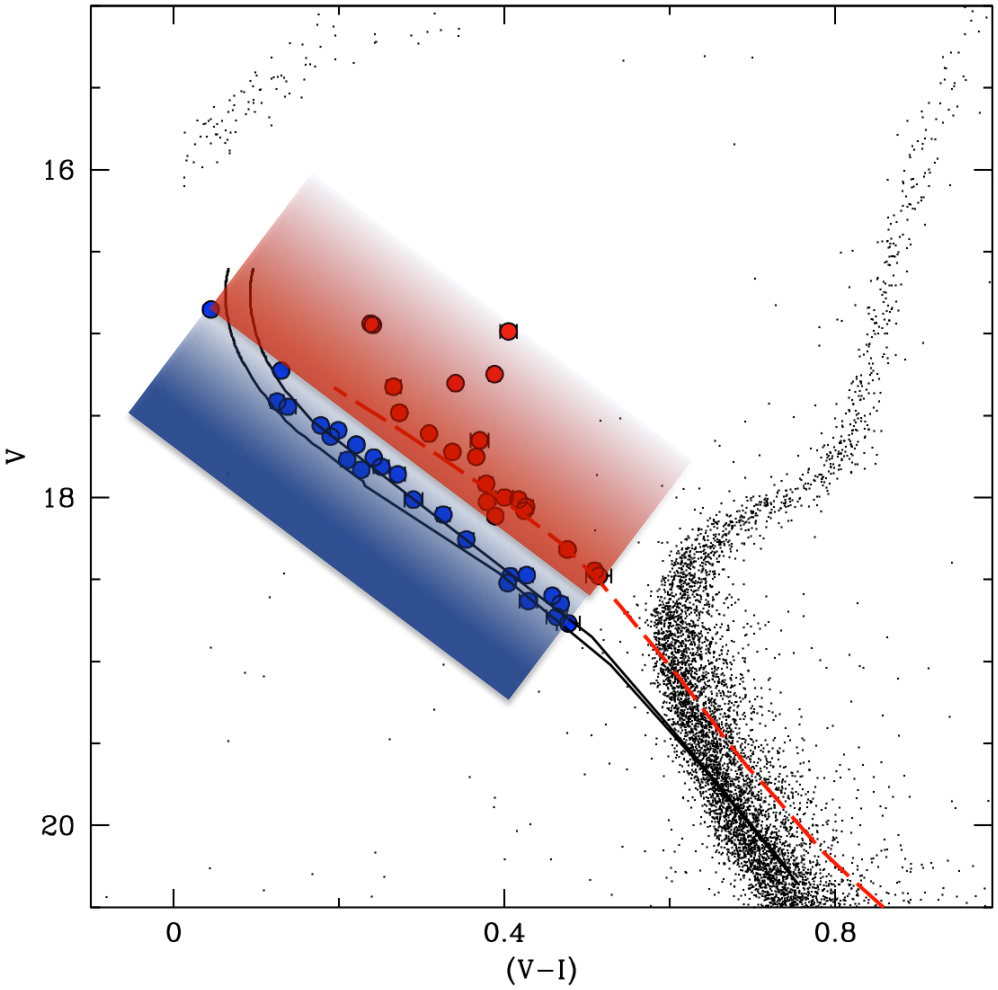
- **blue-BSS → collisional**
- **red-BSS → mass-transfer binaries**

- both will quickly evolve

  → gap filled in a few Gyr

The blue-BSS population
must have formed 1-2 Gyr ago

cluster core-collapse occurred 1-2 Gyr ago and boosted the formation of (at least) the COL-BSS



CONCLUSIONS

1. **BSS are crucial probe of cluster dynamics:**
   - Flat radial distribution (lack of mass segregation)
   - Bimodal distribution (intermediate dynamical age)
   - Monotonic distribution (evolved stages of dynamical evolution)

The BSS radial distribution is a calibrated dynamical clock

2. **BSS can even allow to date catastrophic events:**
   - The double BSS sequence in M30 and NGC362 is likely to be due to the collapse of the core

Thank you!

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