Probing the dynamical evolution of stellar aggregates with BSS radial distribution

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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

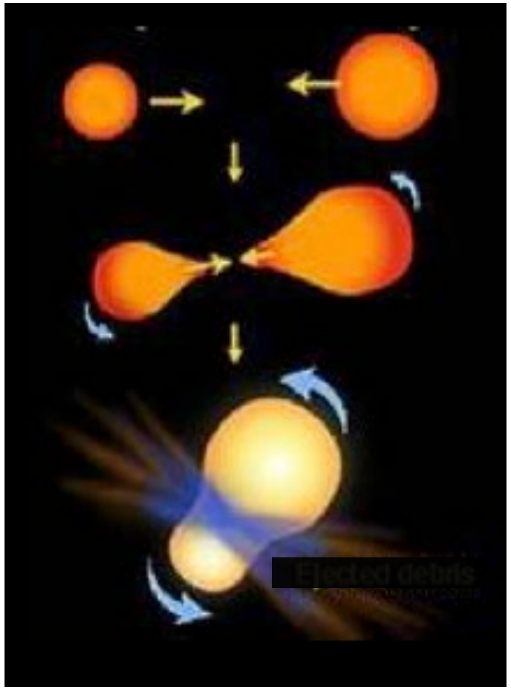
  Blue Straggler Stars
  Millisecond Pulsars
  Intermediate-mass Black Holes

  } as probe-particles

BSS as dynamical probes: why?

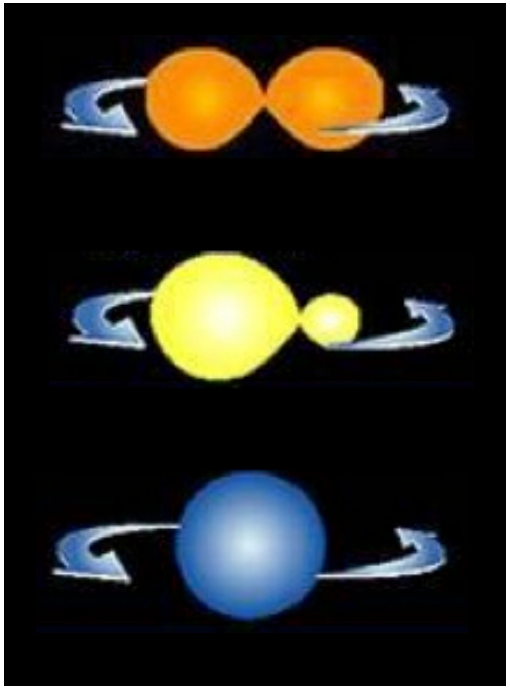
1)

COLLISIONAL BSS



depend on **collision** rate

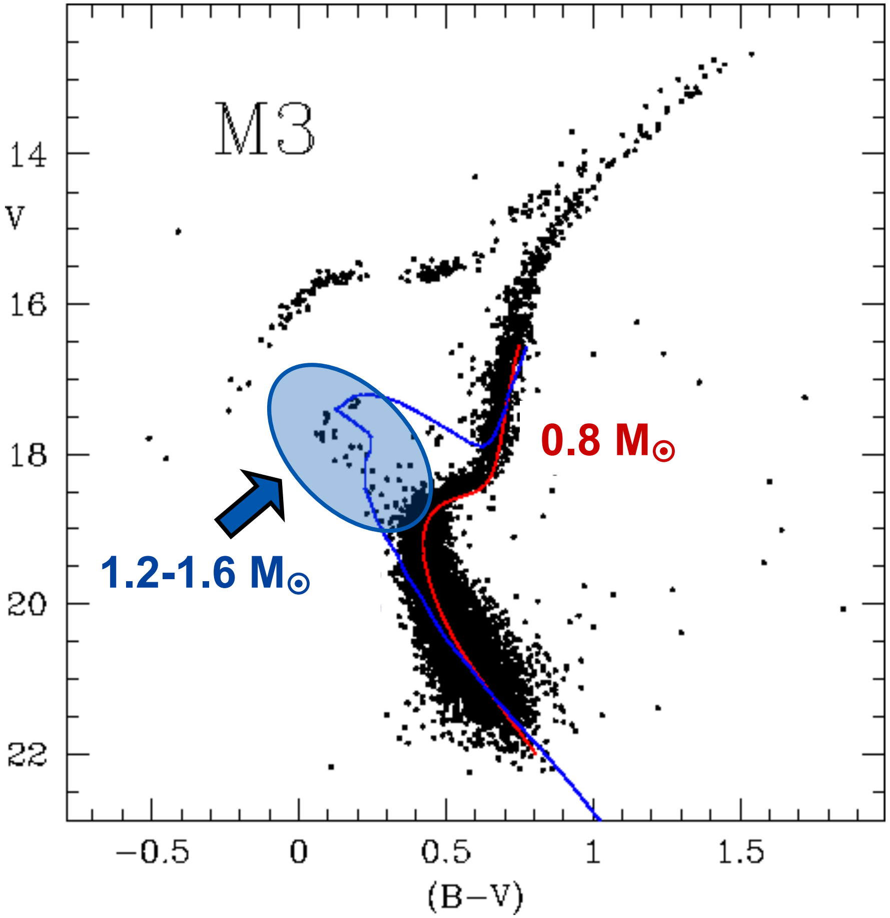
MASS-TRANSFER BSS



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

BSS as dynamical probes: why?

2)



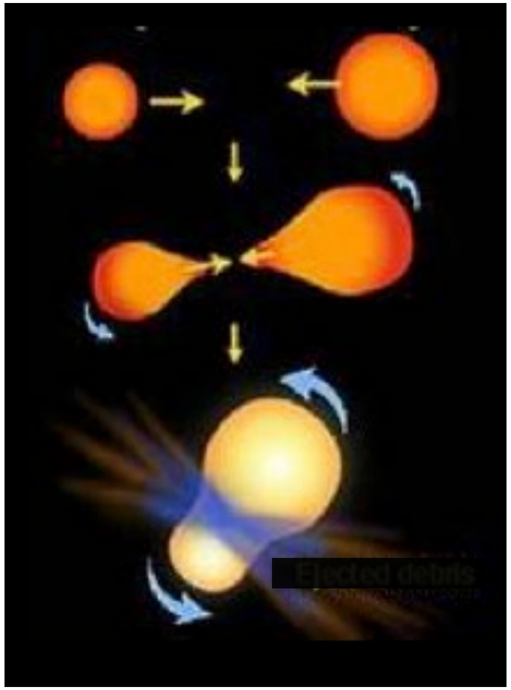
• BSS (both COL- & MT-) **more massive** than the average

• progenitors of MT-BSS (binaries) **more massive** than the average

suffer from the effects of **dynamical friction**

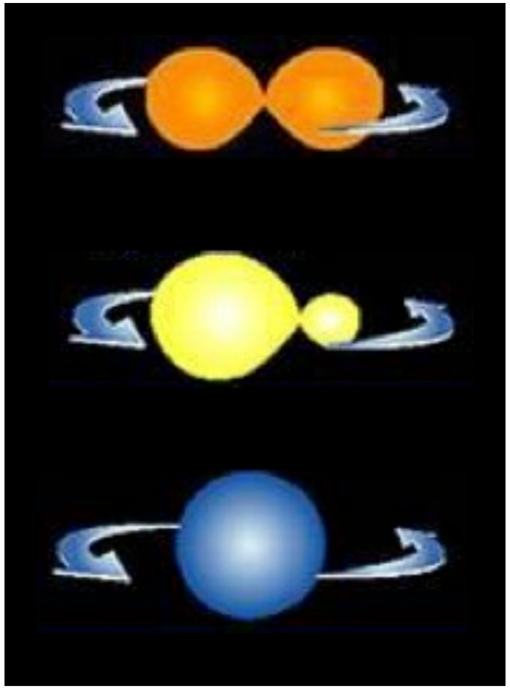
BSS as dynamical probes: why?

collisional BSS



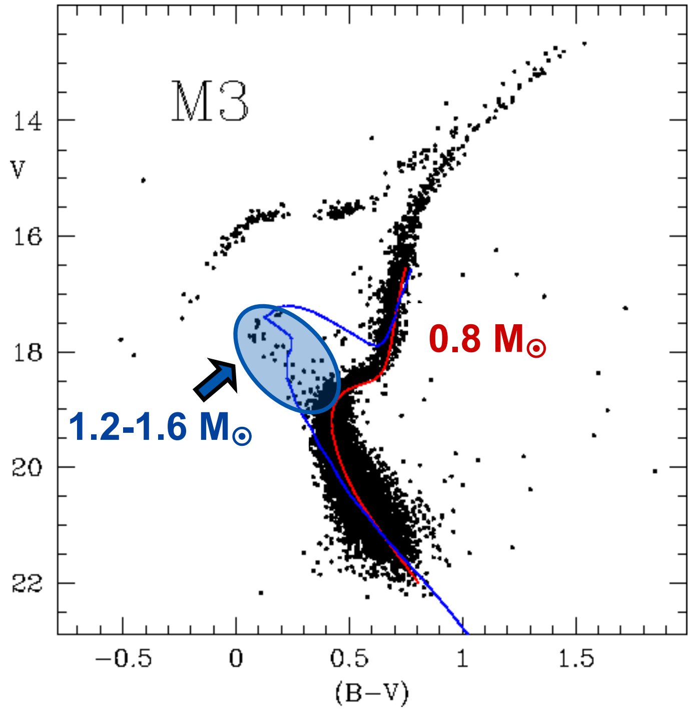
collisions

mass-transfer BSS



dynamical interactions

more massive than average



dynamical friction

BSS: crucial probes of stellar dynamics

BSS RADIAL DISTRIBUTION as dynamical probe: why?

collisions
dynamical interactions

- most frequent in high-density **central regions**

dynamical friction

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

BSS at all radial distances provide information on dynamical processes

BSS RADIAL DISTRIBUTION: METHODOLOGY

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

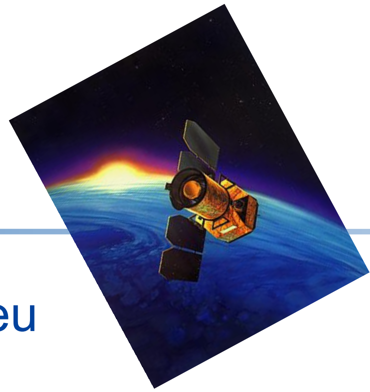
↓

HST (WFPC2, ACS, WFC3)

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

↓

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

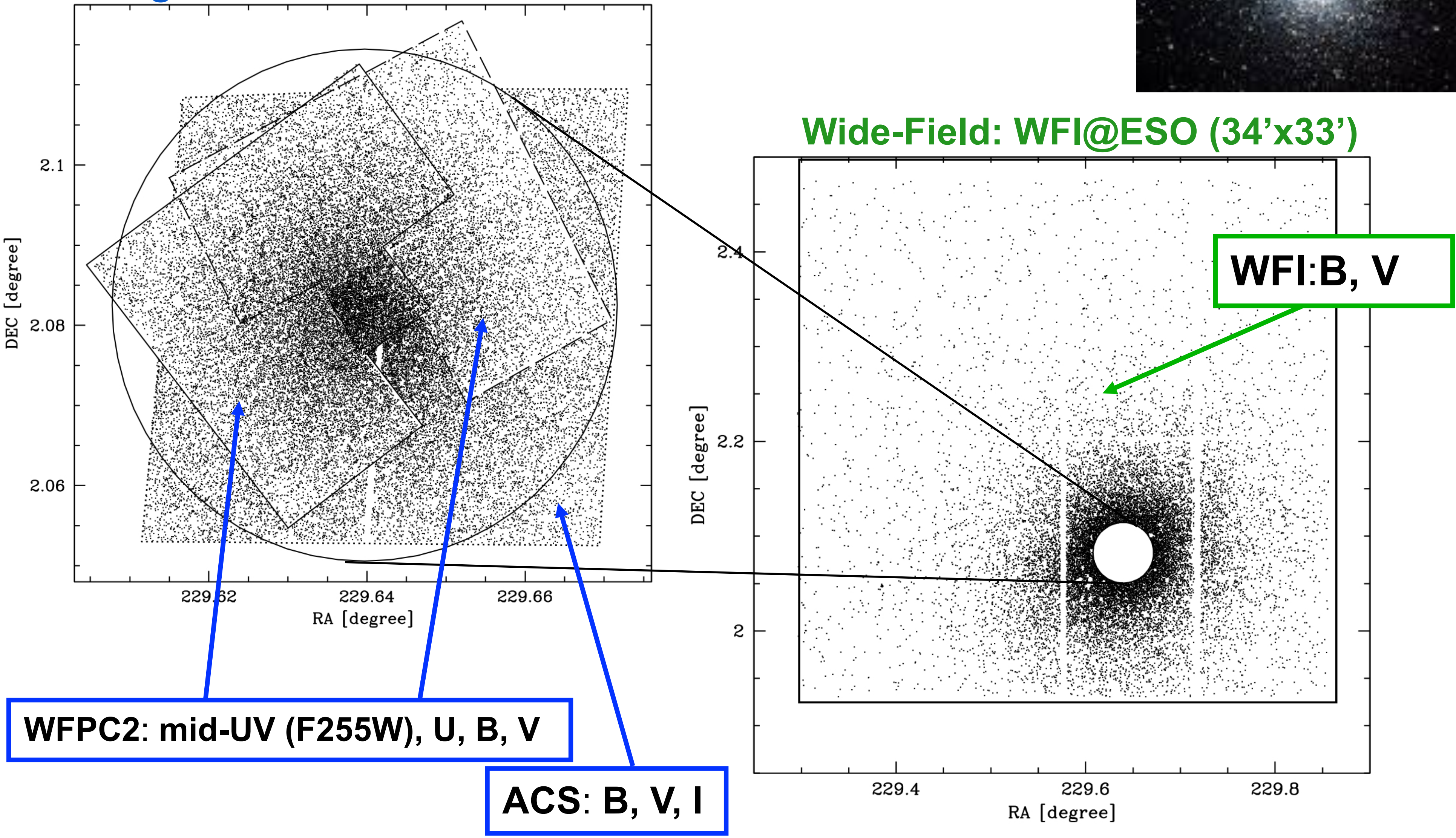


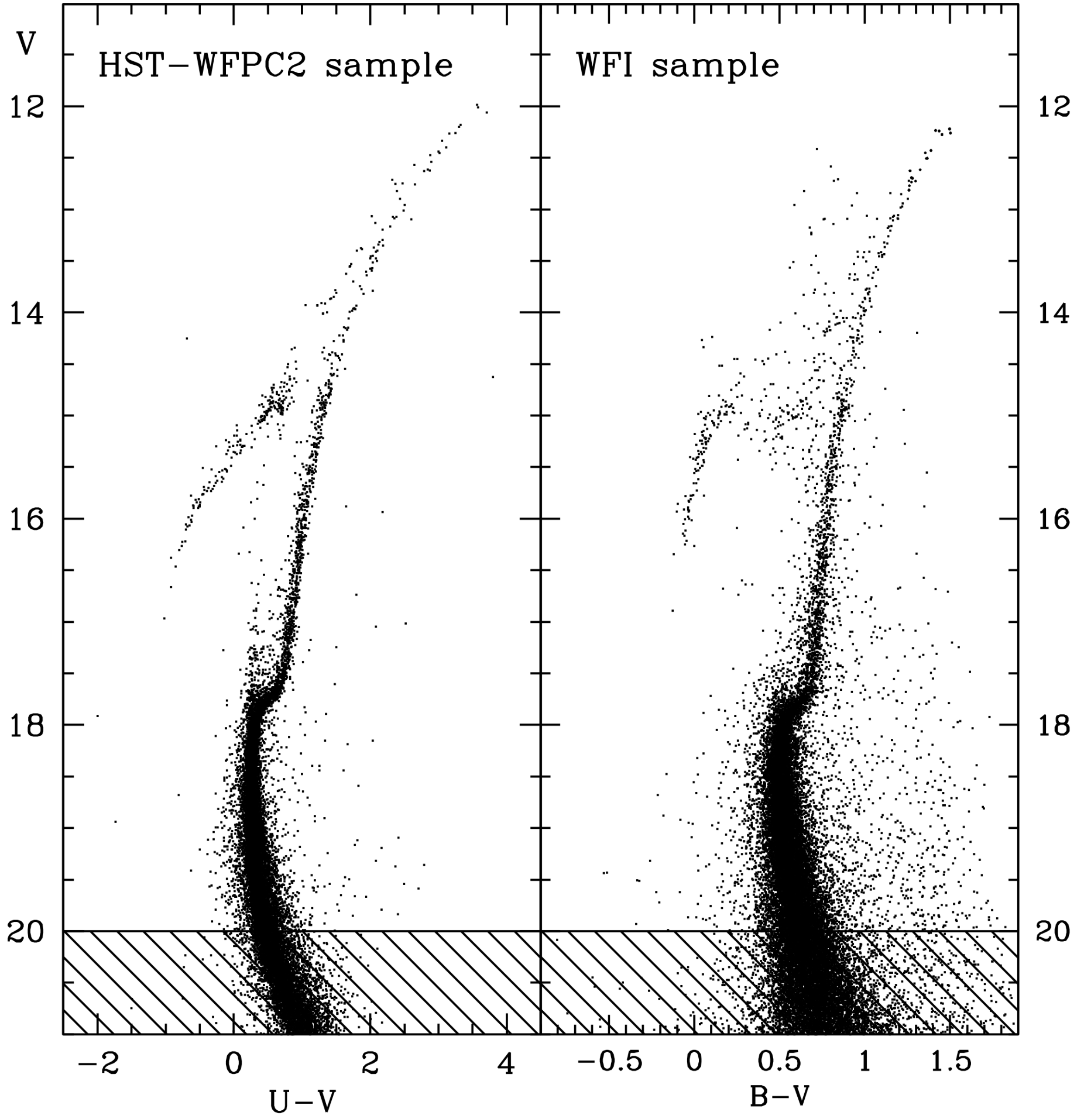
Data-set

M5 (NGC5904)

High-Res: HST/WFPC2+ACS

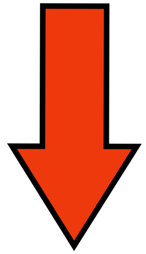
Wide-Field: WFI@ESO (34’x33’)





large & complete samples of resolved stars

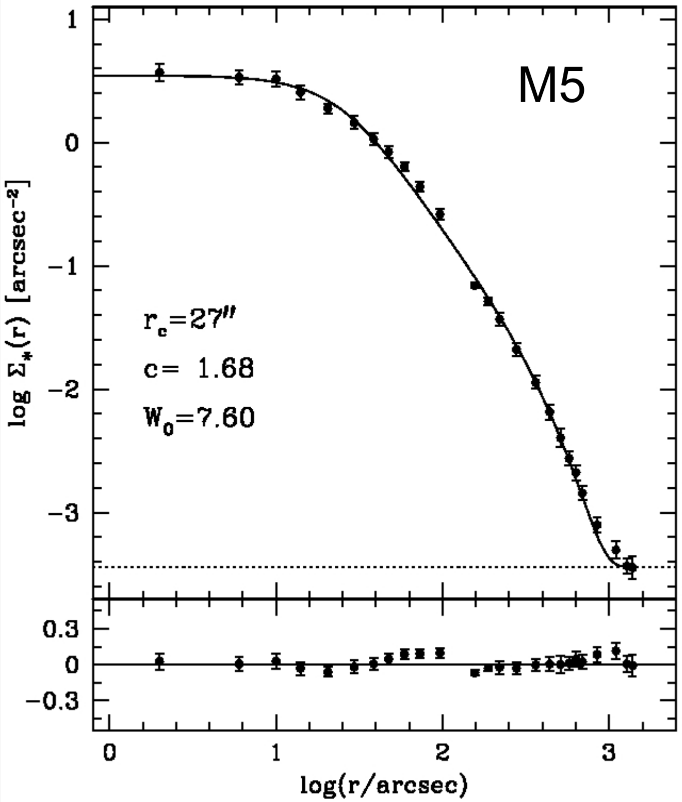
all over the entire cluster extension



Centre & density profile from resolved star counts

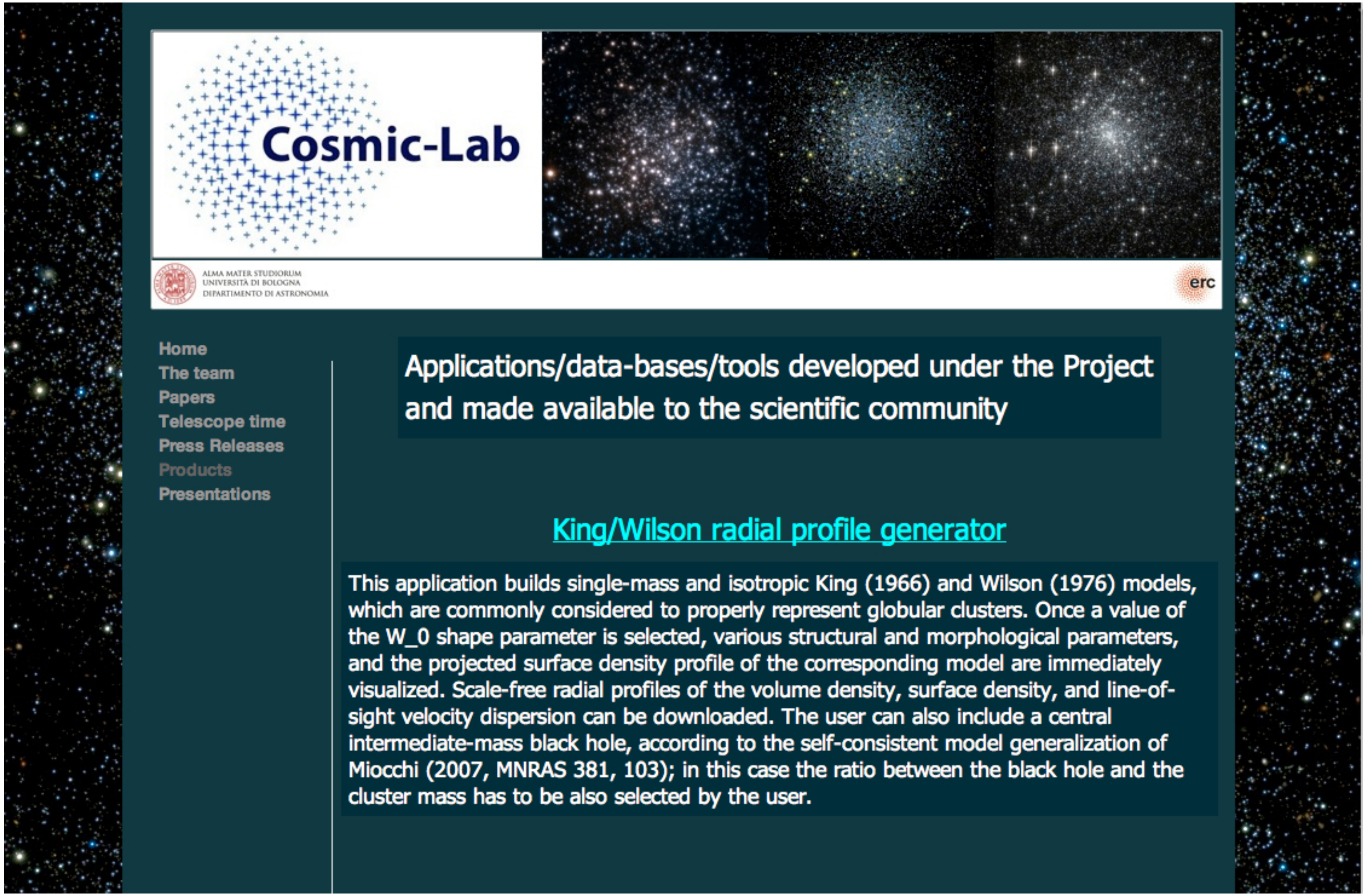
✓ **gravity centre**: average of star positions (+ weighted by local density)
... instead of luminosity centre (bias from a few bright stars)

✓ **density profile:** star counts in concentric annuli
... instead of surface brightness profile (bias from a few bright stars)



★ centres, density profiles, King & Wilson fits and structural parameters for 25 GCs
→ Miocchi et al. 2013

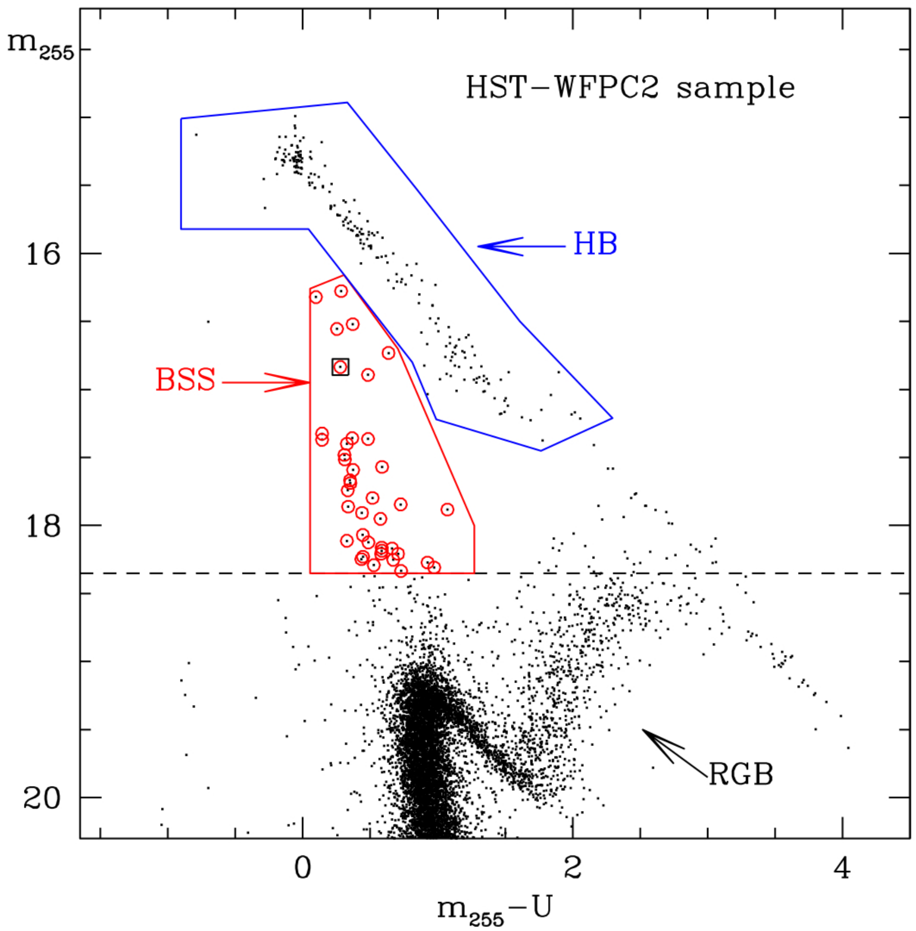
★ **King/Wilson (+IMBH) density & velocity dispersion profiles generator freely available at: www.cosmic-lab.eu/Cosmic-Lab/Products.html**



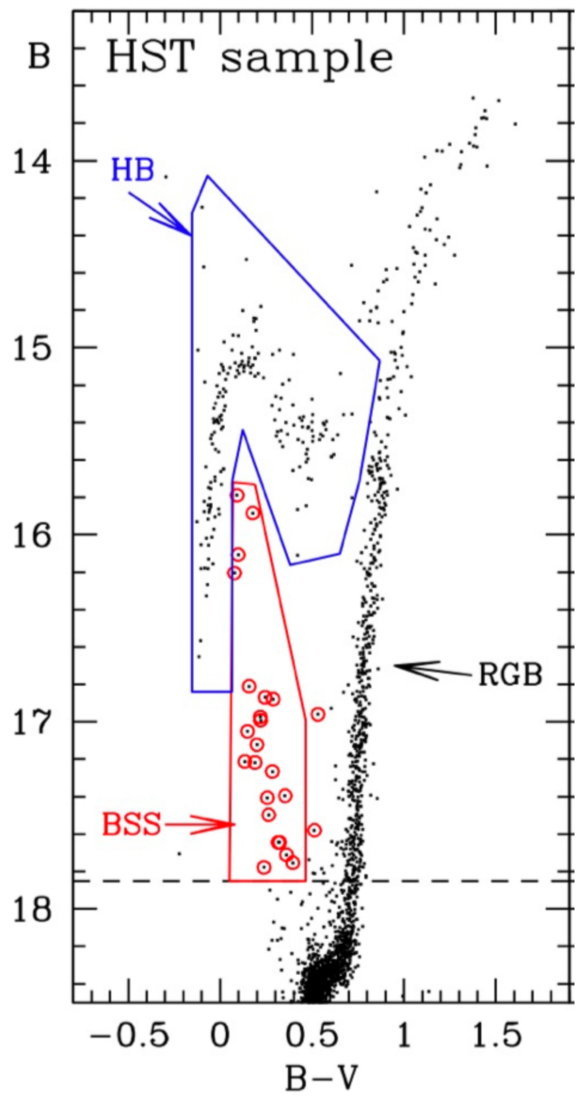
BSS selection

M5 (NGC5904)

UV-plane (HST)



optical plane (HST)



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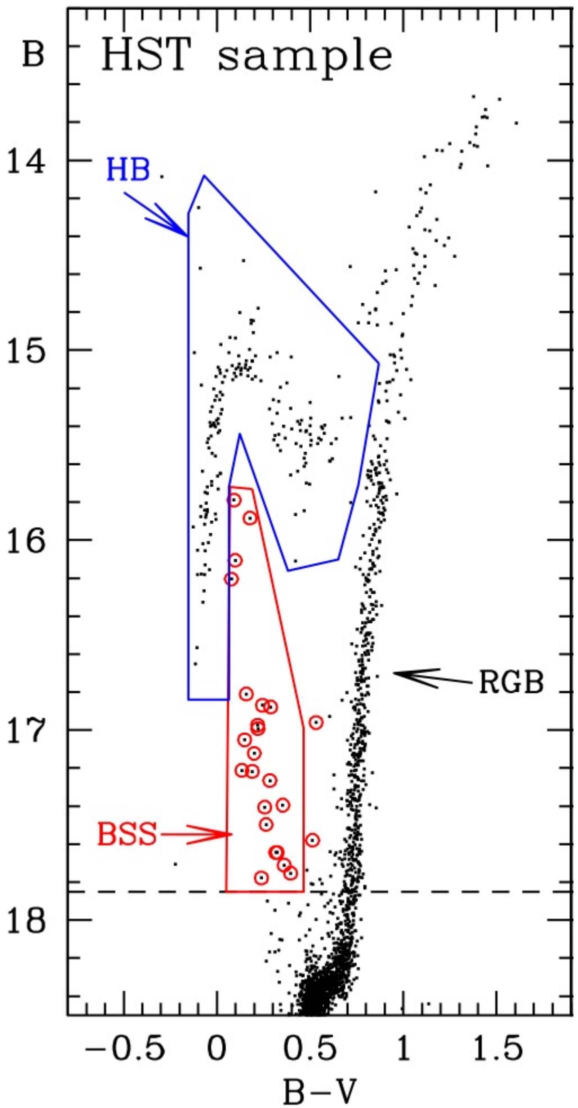
BSS selection

M5 (NGC5904)

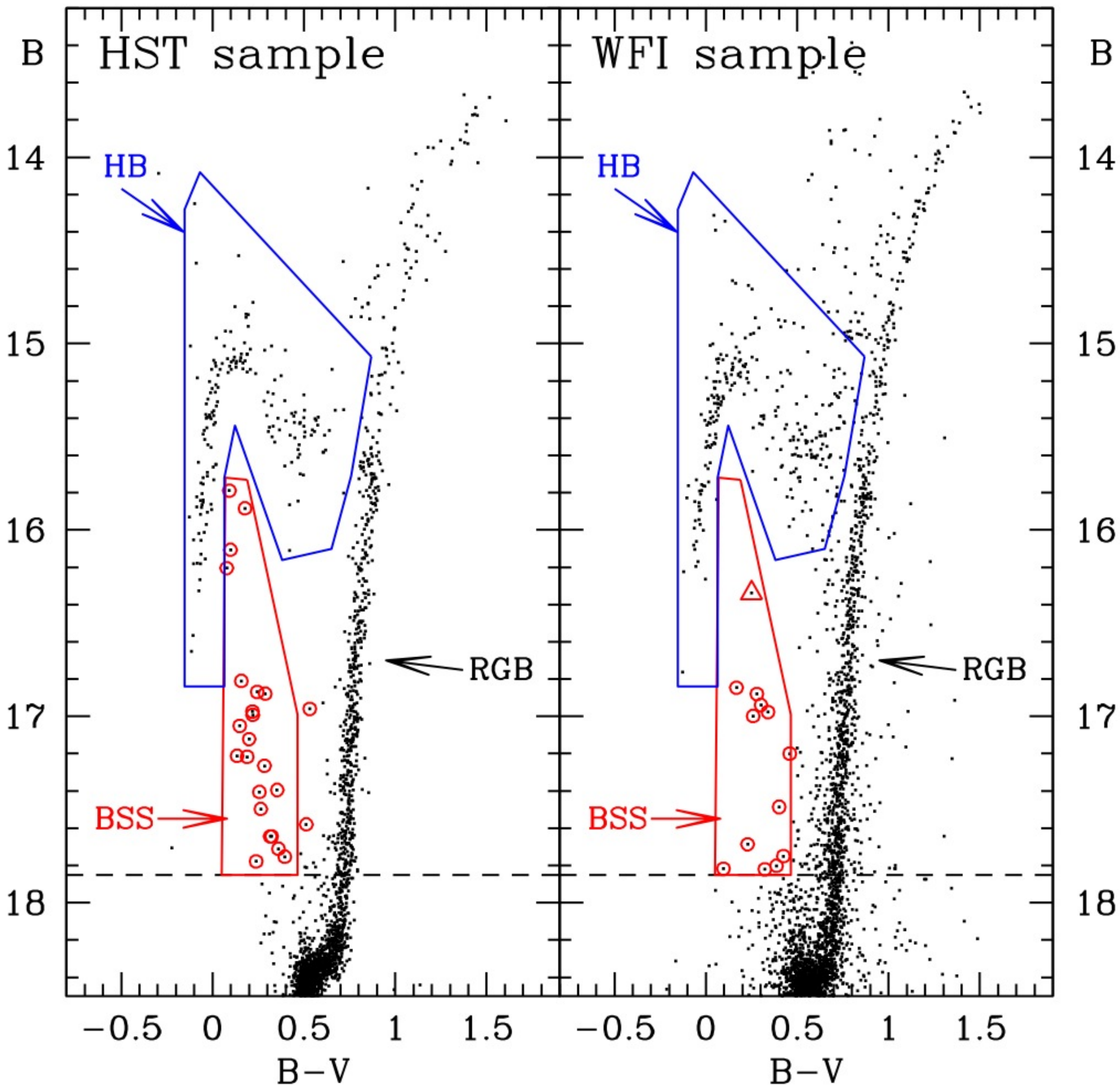
from HST



BSS selection

M5 (NGC5904)

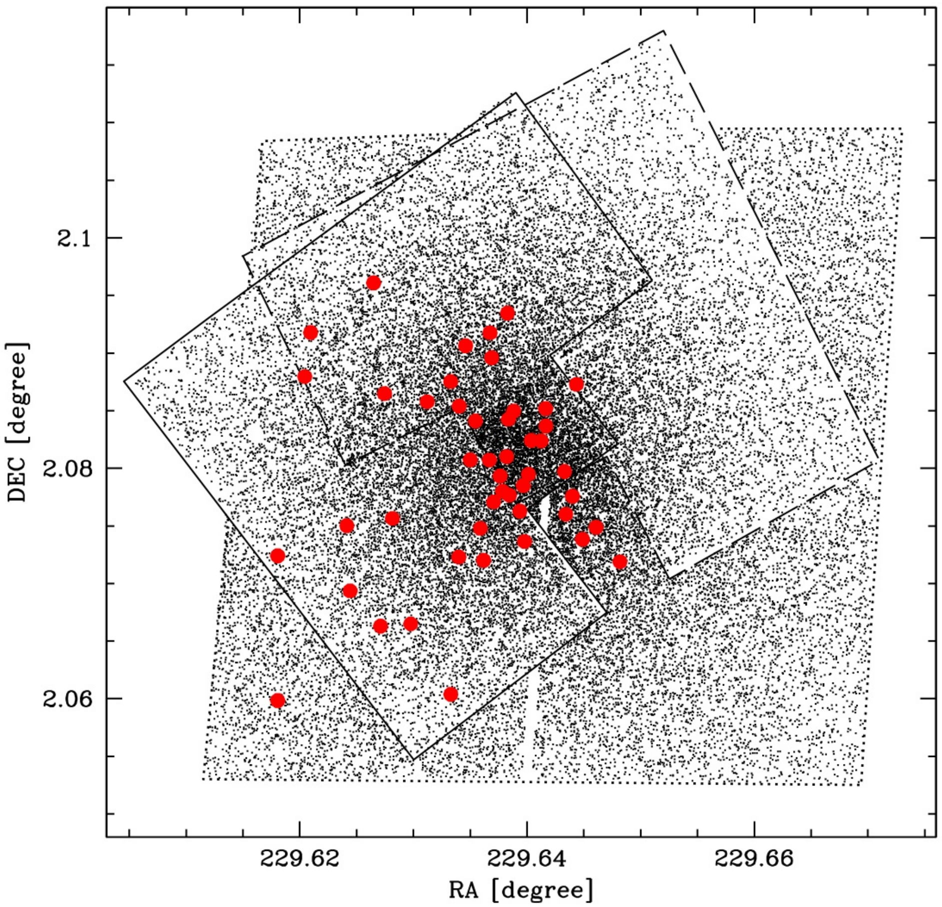
from HST → to ground-based



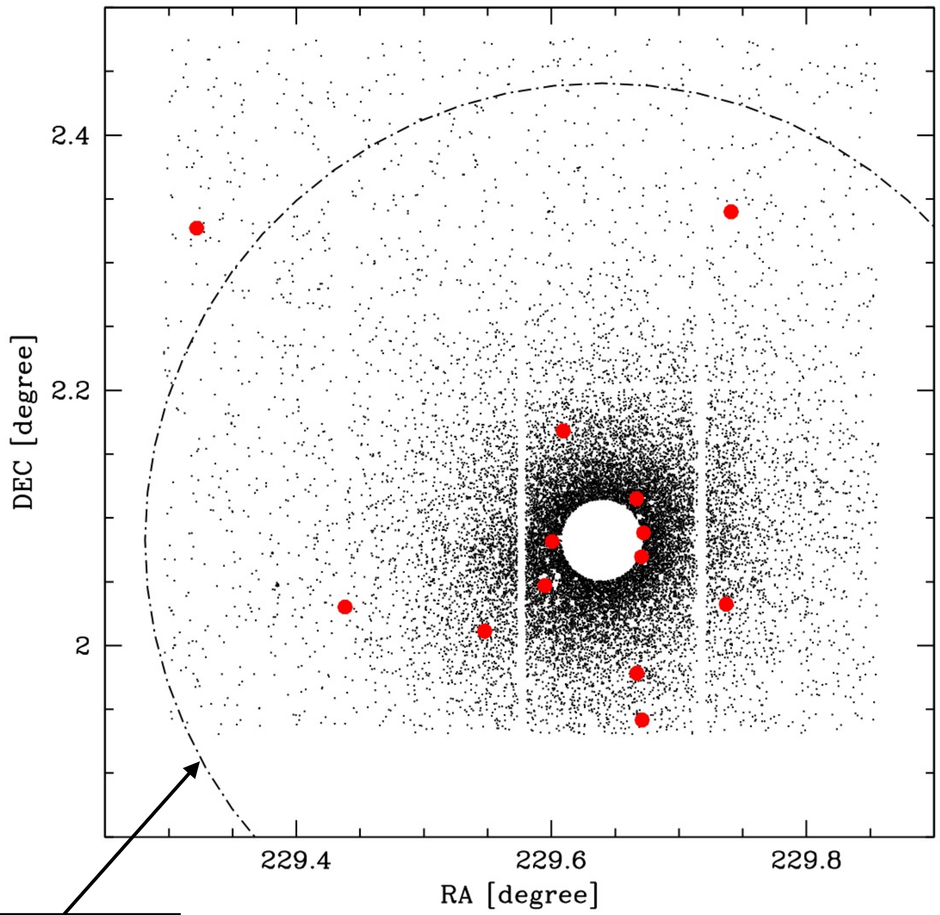
BSS radial distribution

M5 (NGC5904)

High-Res WFPC2+ACS HST



Wide-Field WFI@ESO



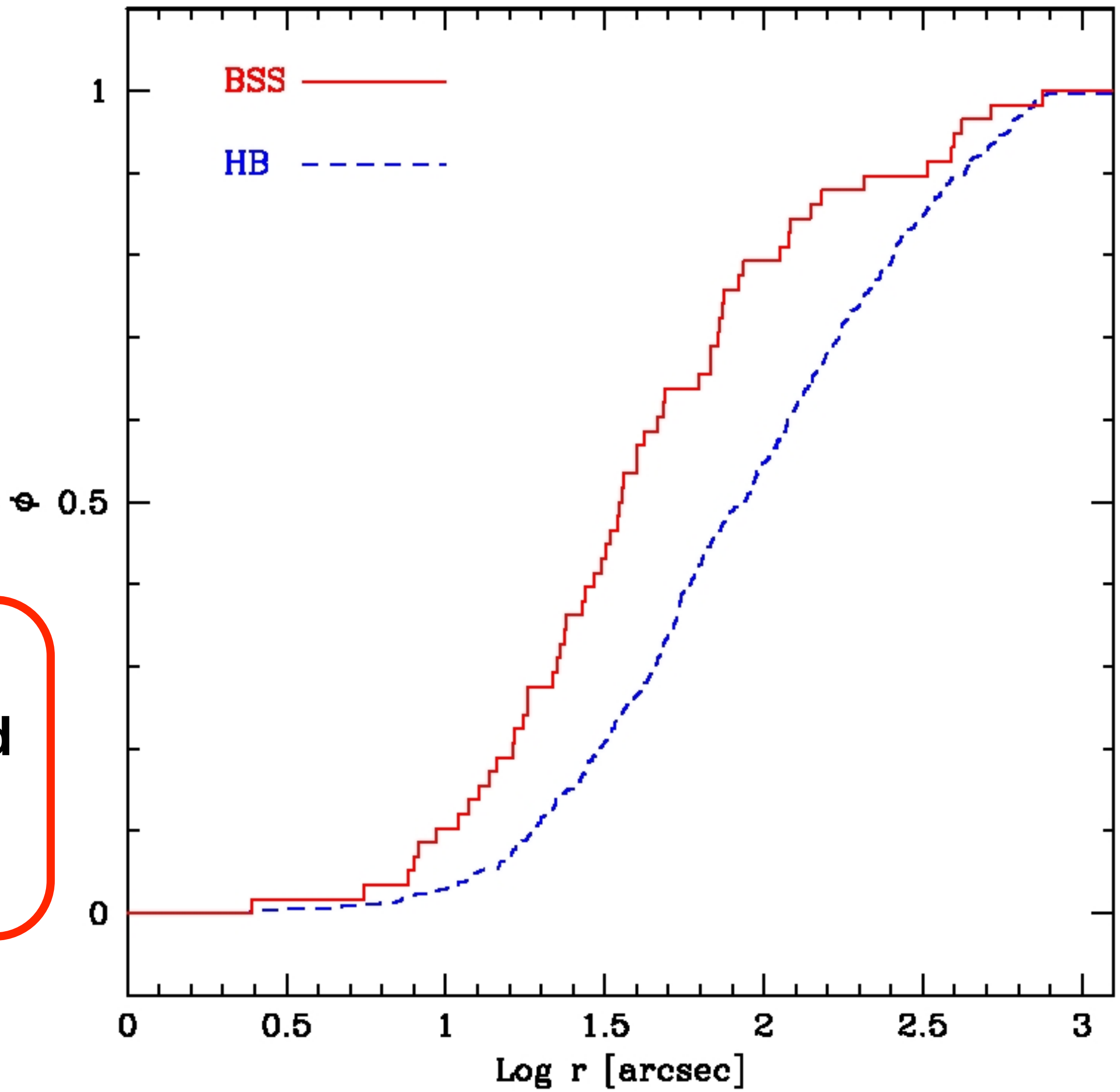
r_t = 21.'5

cumulative radial distribution

M5 (NGC5904)

KS-test:
10^{-4} probability that BSS and HB stars are extracted from the same population

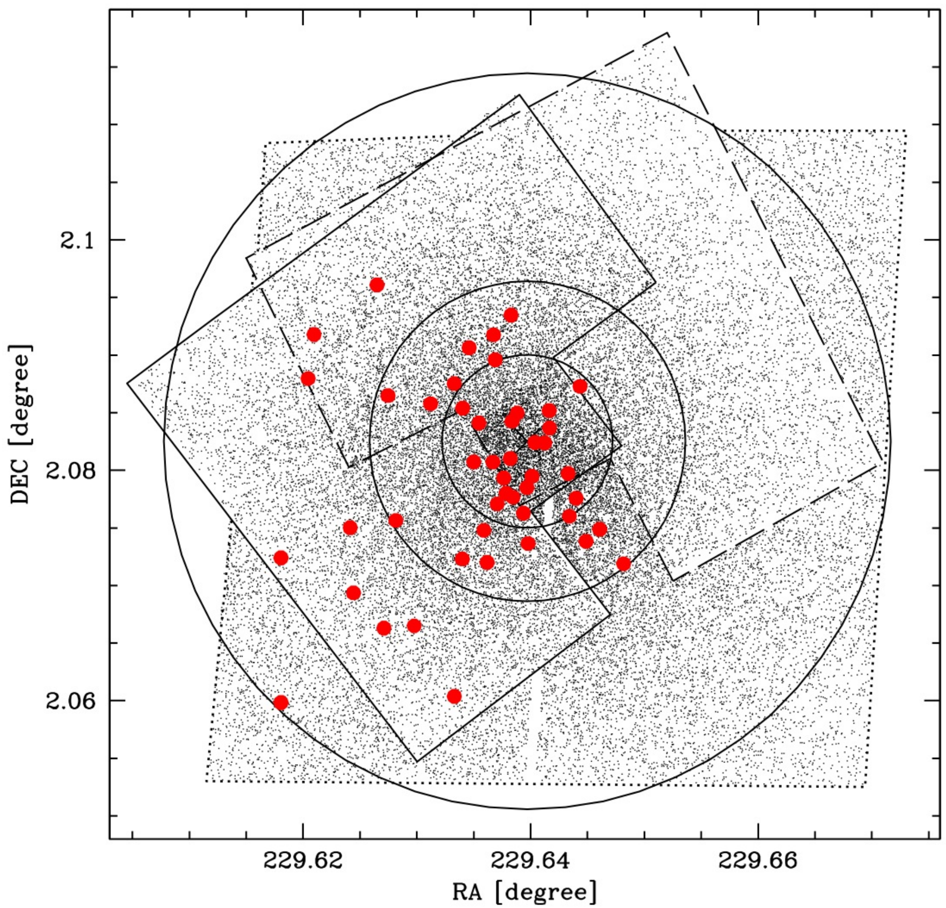
BSS are more centrally concentrated than HB at more than 4σ level



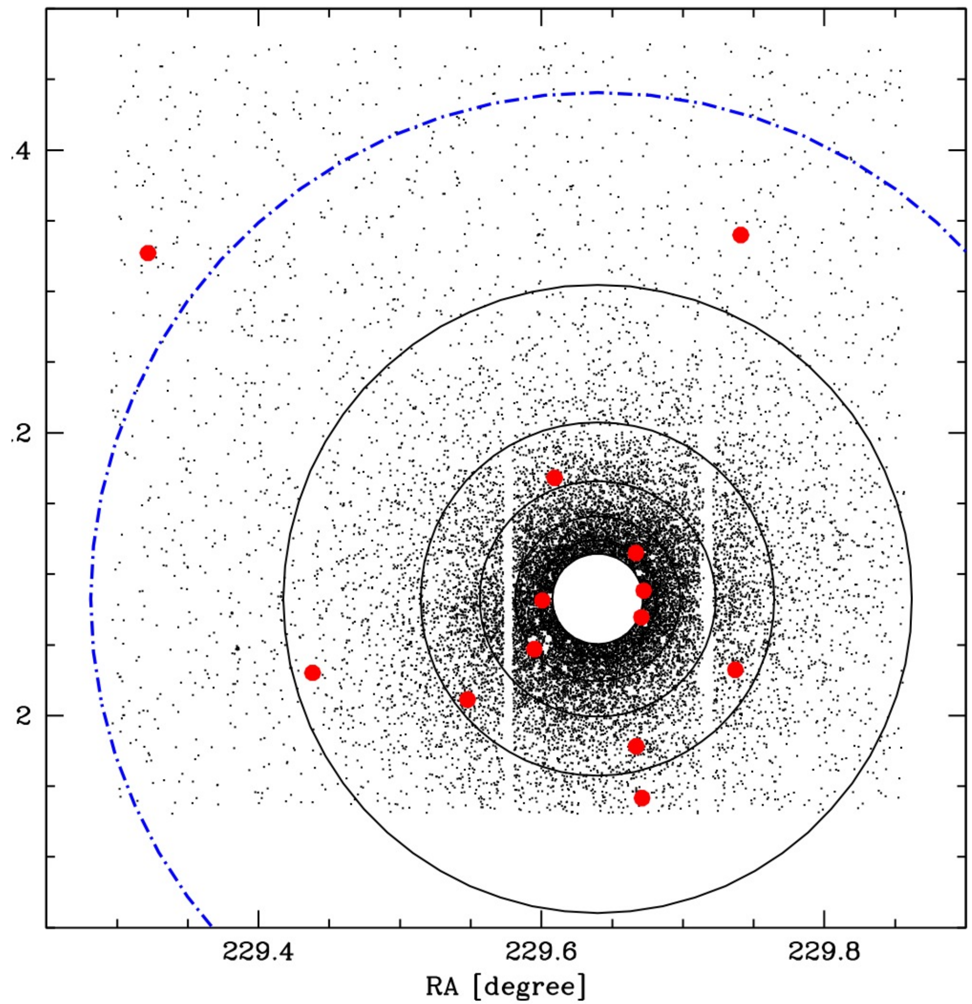
BSS radial distribution

M5 (NGC5904)

High-Res WFPC2+ACS HST

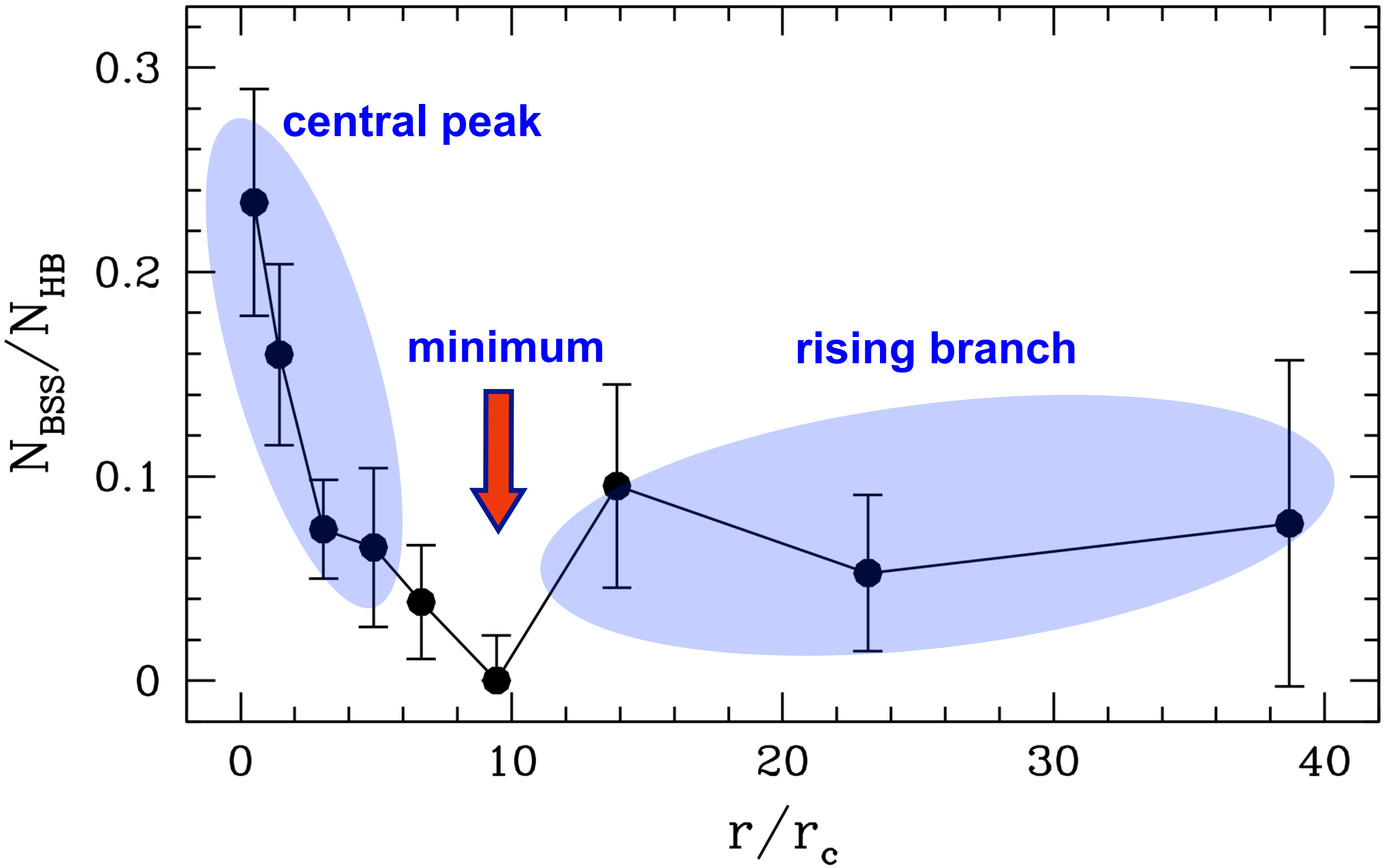


Wide-Field WFI@ESO



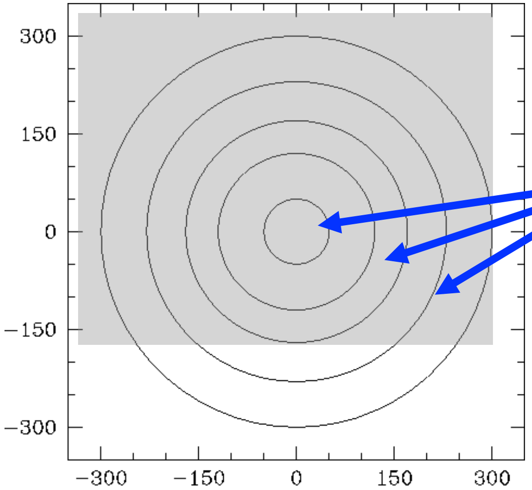
Specific frequency

M5 (NGC5904)



Doubled normalized ratio

M5 (NGC5904)



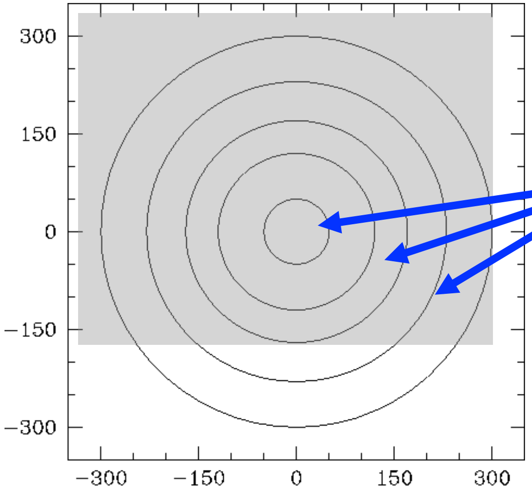
$$R_{HB} = \frac{N_{HB}/N_{HB,TOT}}{L_{samp}/L_{TOT}}$$

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

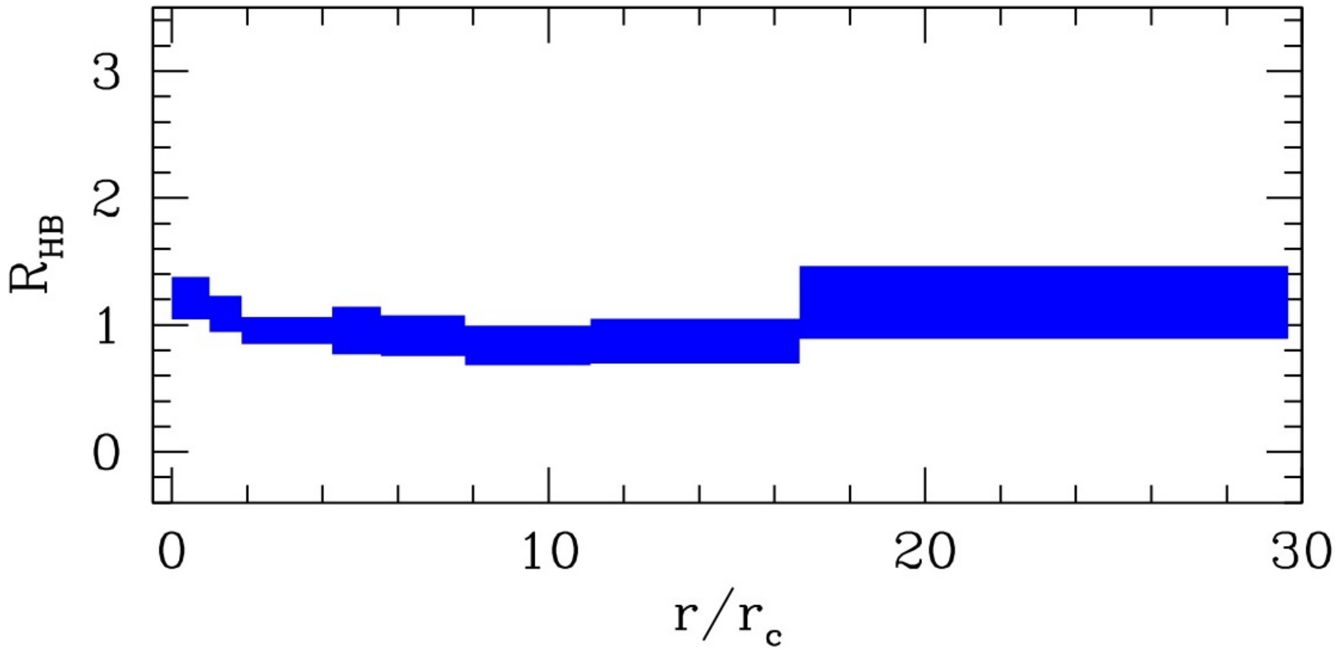
(from *The Consumption Theorem*
Renzini & Buzzoni 1986; Renzini & Fusi Pecci 1988)

Doubled normalized ratio

M5 (NGC5904)



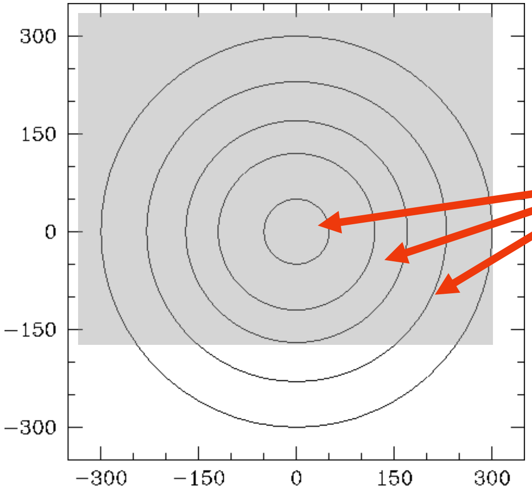
$$R_{HB} = \frac{N_{HB}/N_{HB,TOT}}{L_{samp}/L_{TOT}}$$



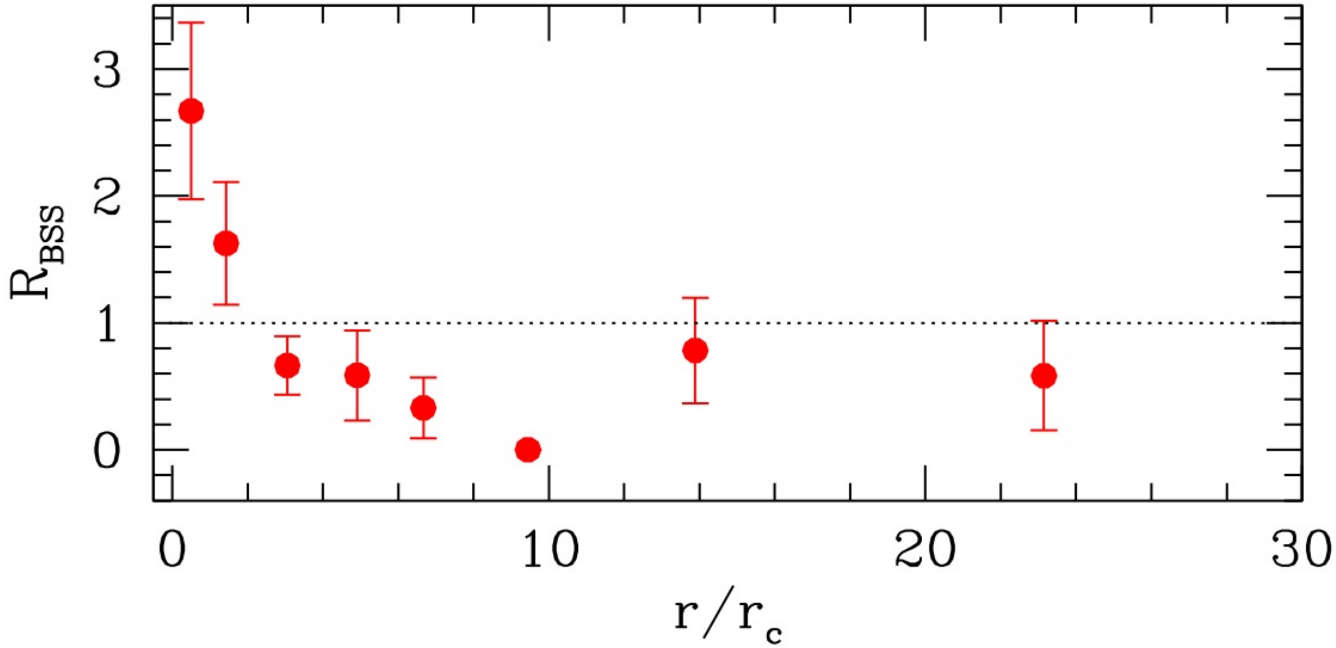
HB stars NOT segregated in the centre

Doubled normalized ratio

M5 (NGC5904)

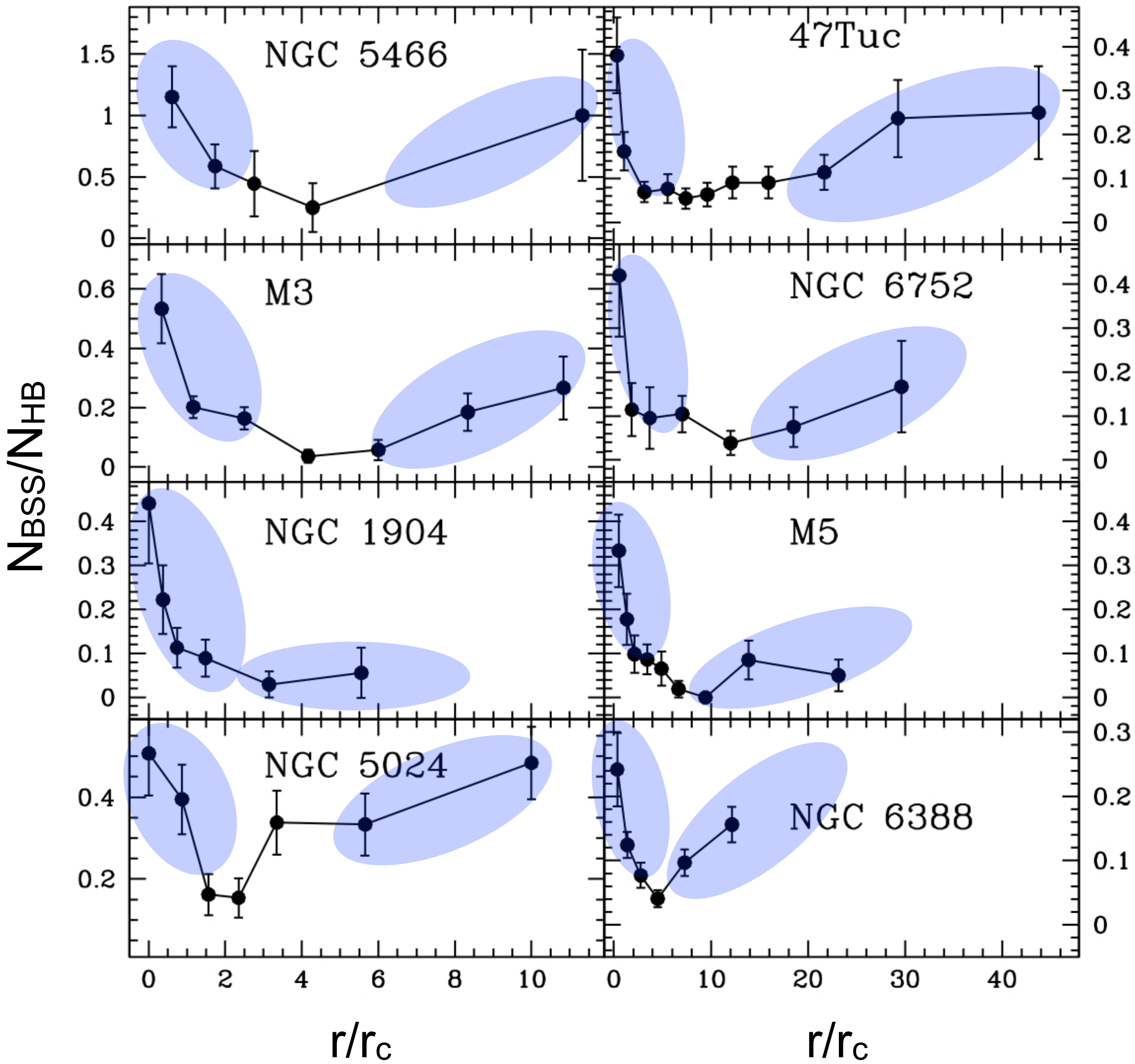


$$R_{BSS} = \frac{N_{BSS}/N_{BSS,TOT}}{L_{samp}/L_{TOT}}$$



BSS are highly segregated in the centre

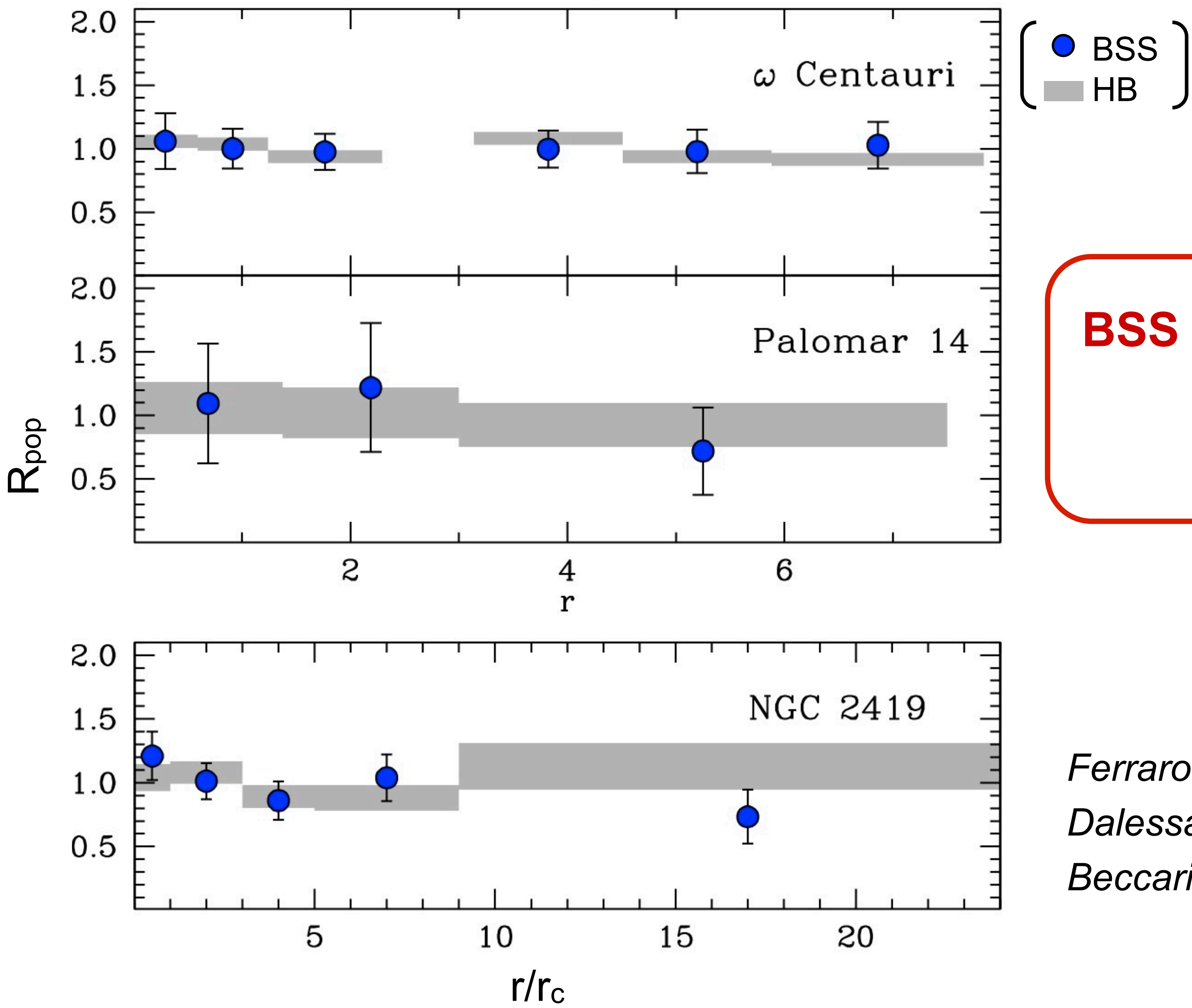
Results (1)



BSS radial distribution centrally peaked/bimodal in most (~18) GCs

Ferraro et al. (93, 94, 04);
Sabbi et al. (04);
Lanzoni et al. (07ab);
Dalessandro et al. (08);
Beccari et al. (08, 09);
Contreras Ramos et al. (12);
Sanna et al. (12)
...

Results (2)



BSS radial distribution
FLAT
in 3 cases

Ferraro et al. (2004);
Dalessandro et al. (2008);
Beccari et al. (2011)

What do we learn about cluster dynamics?

(1)

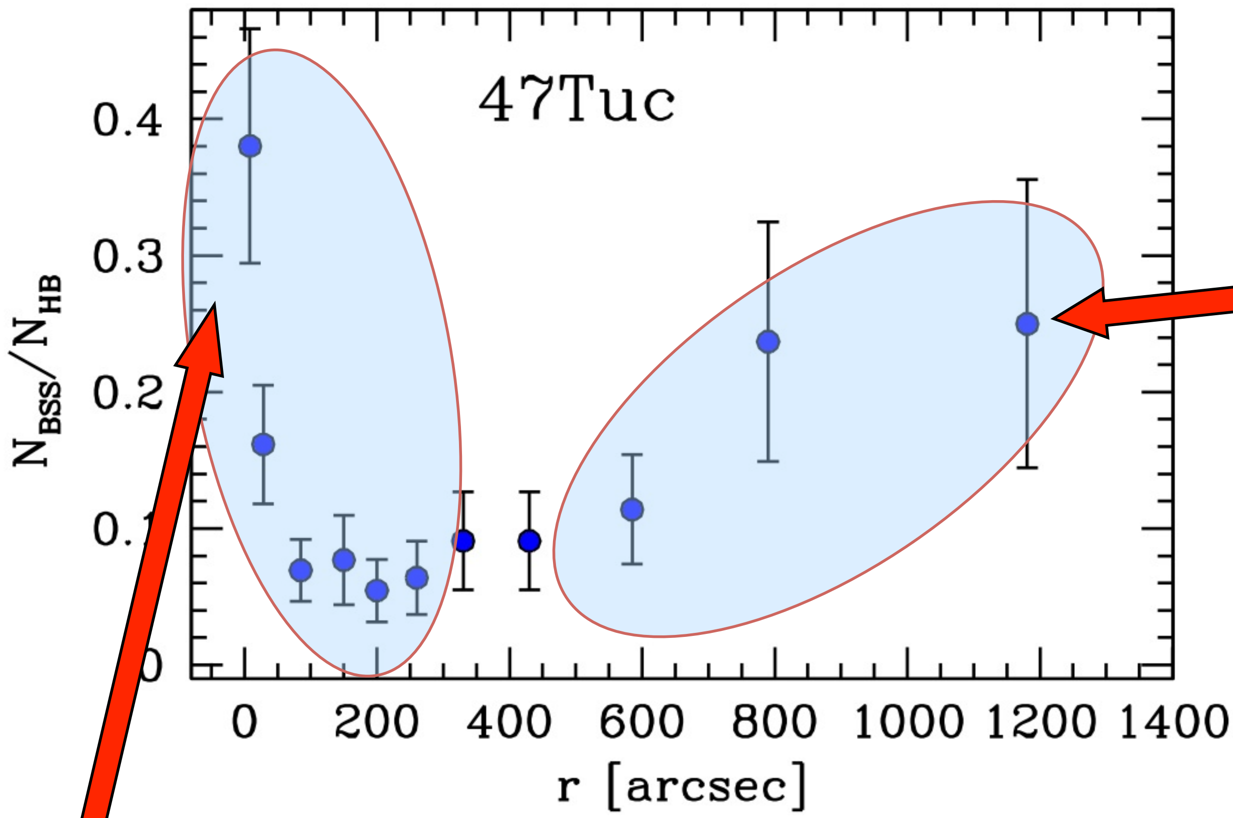
- BSS more massive than average (→ dynamical friction)
- flat BSS radial distribution in 3 cases

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

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

What do we learn about cluster dynamics?

(2)



COL-BSS kicked out from cluster core

or

MT-BSS

COL-BSS formed in the core
or
MT-BSS sunk to the centre (dynamical friction)

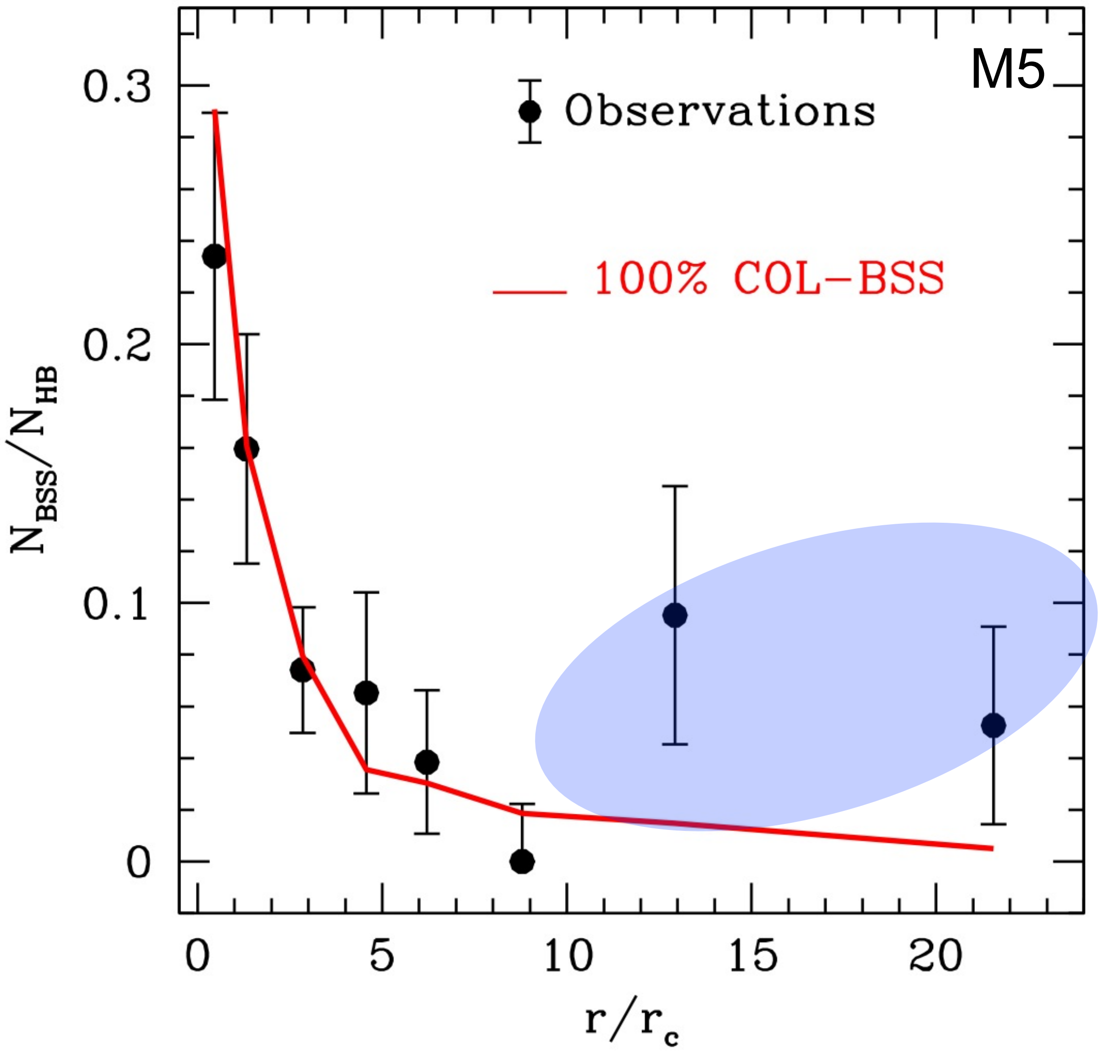
Monte-Carlo simulations of BSS evolution (Sigurdsson & Phinney 1995):

- **Background cluster:**
  multi-mass King model that best fits the observed profile

- **Two populations of BSS:**
  "COL-BSS": generated within r_c, with natal kick velocity
  "MT-BSS": generated from primordial binaries at $r >> r_c$, with no natal kick

- **Dynamical evolution due to:**
  dynamical friction and distant encounters

Monte-Carlo simulations of BSS evolution

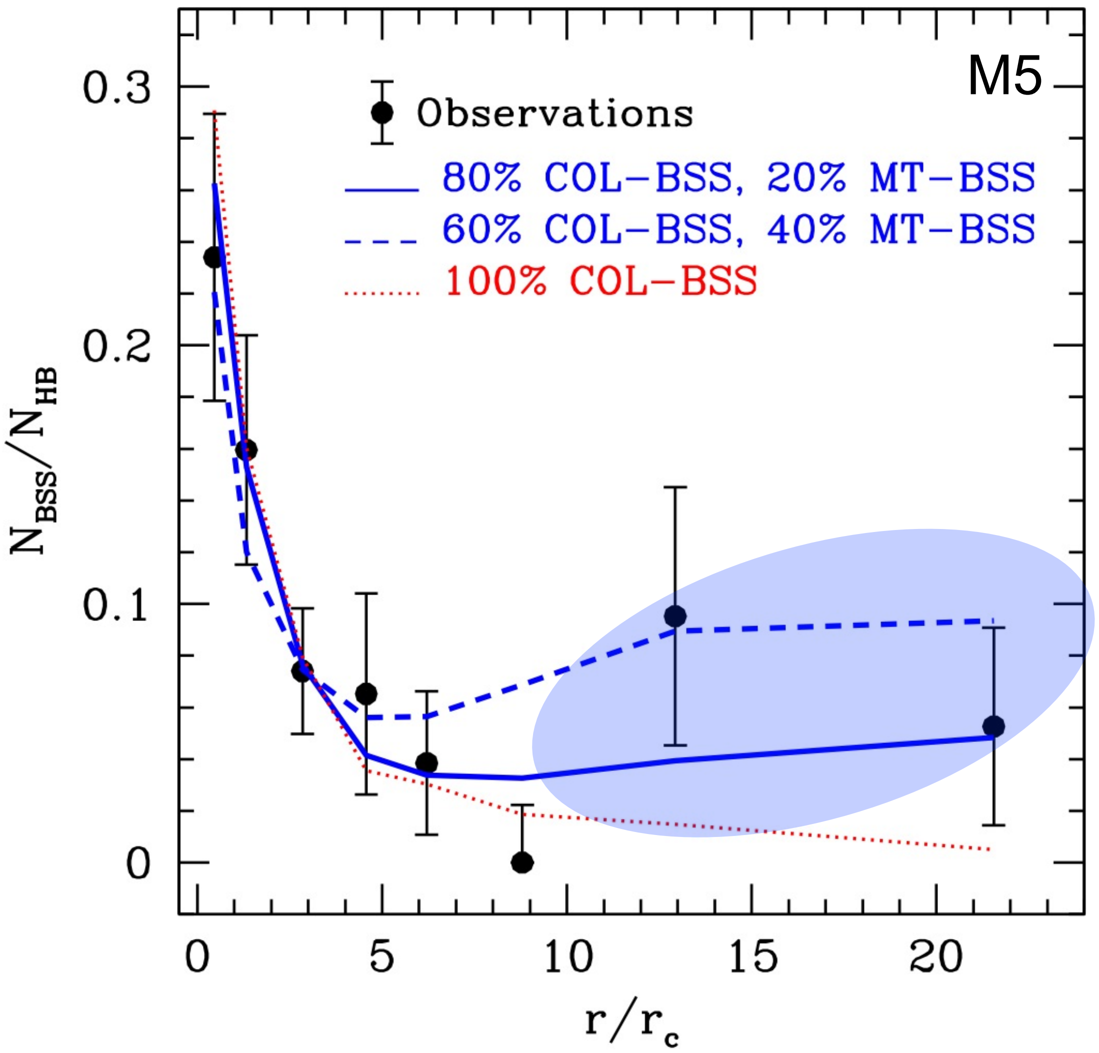


COL-BSS kicked out from the core sink back in just 1-2 Gyr

Mapelli et al. 2004, 2006
Lanzoni et al. 2007a,b

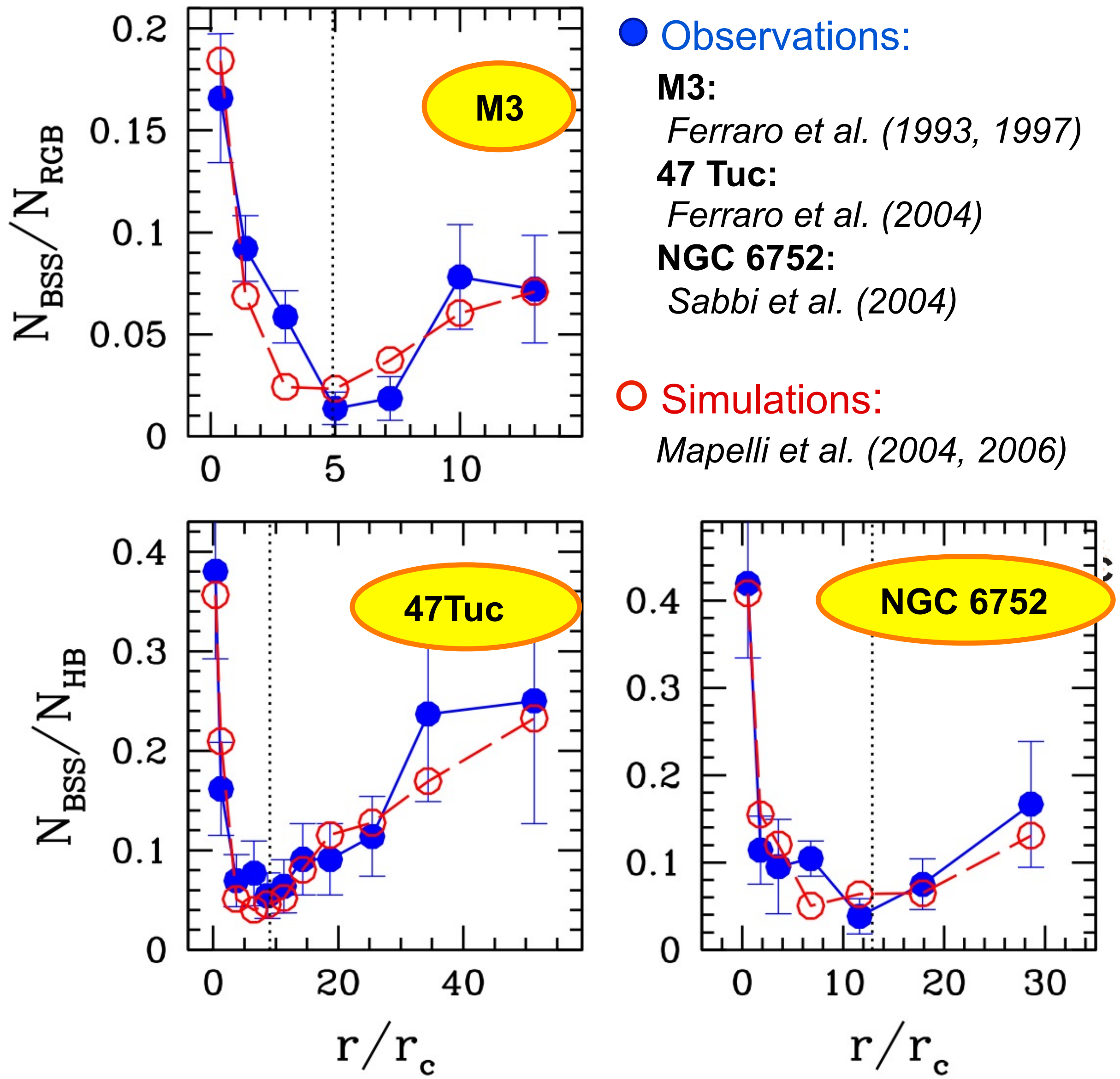
COL-BSS only CANNOT to reproduce the external rising branch

Monte-Carlo simulations of BSS evolution



MT-BSS needed to reproduce the population observed in the outskirts

Monte-Carlo simulations of BSS evolution



cluster	COL-BSS	MT-BSS
M3	42%	58%
47 Tuc	30%	70%
NGC6752	45%	55%

% of two kinds of BSS varies from cluster to cluster

Radius of avoidance

r_{avoid} = radius within which all stars of M~ M_{BSS}
have sunk into the cluster centre
in a time comparable to the cluster age
because of dynamical friction:

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

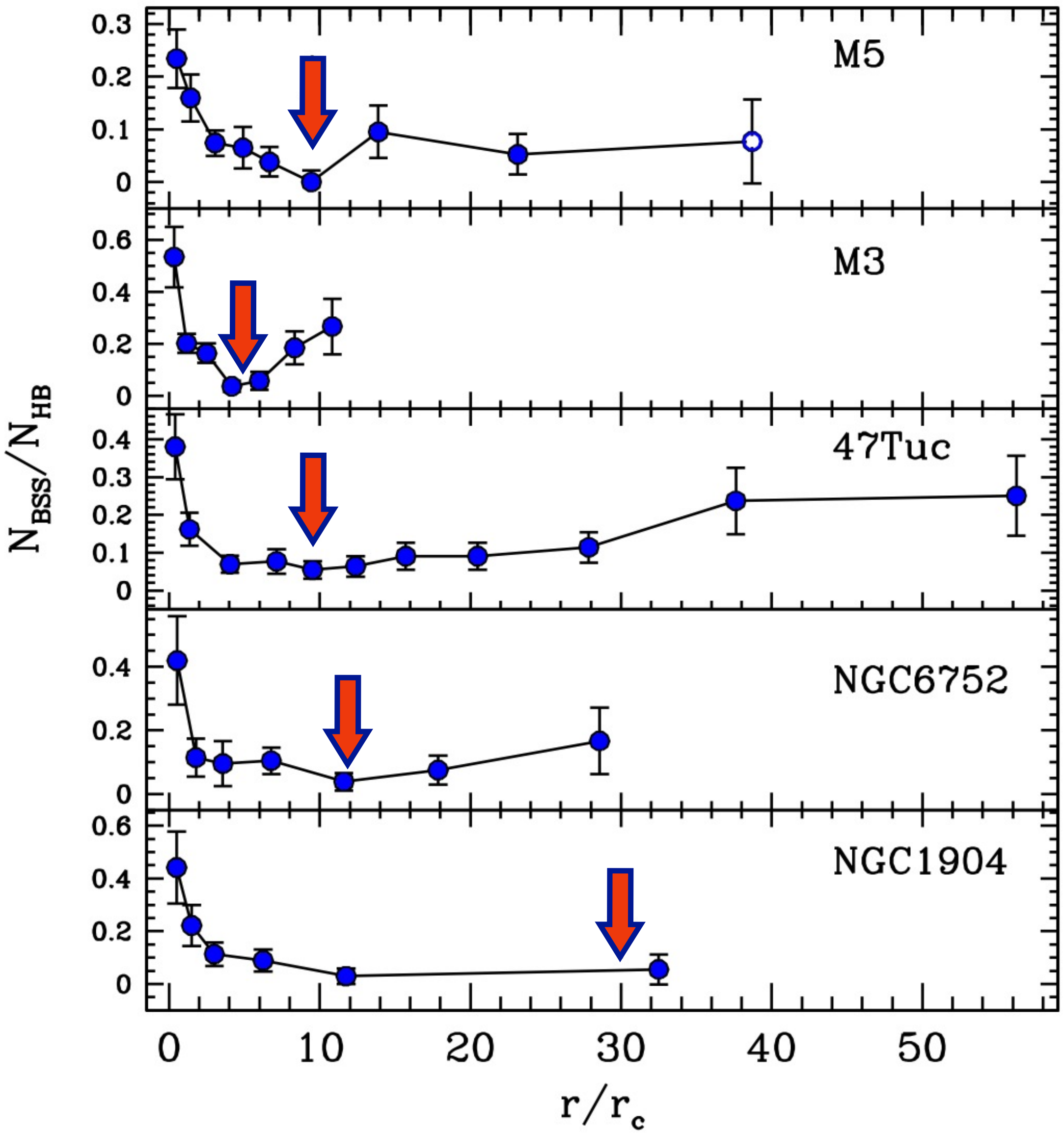
where:

M_{BSS} = 1.2 Msol

t_{AGE} = 12 Gyr

$\rho(r)$, $\sigma(r)$ from best-fit King model of the observed density profile

Radius of avoidance



r_{avoid} well agrees with the position of the observed minimum

tight link between the minimum position and dynamical friction

Conclusions

(1) BSS radial distribution crucial probe of cluster dynamics:

- central peak: COL-BSS & MT-BSS
- external portion: MT-BSS
- position of the minimum: tracer of dynamical friction efficiency
- flat distribution: lack of mass segregation (even in the core)

(2) quantitative details still need to be fully understood

- increase statistics & compare to cluster properties
- compare to open clusters & dwarf galaxies
- determine radial distribution of binary systems (quite challenging...)
- run realistic N-body simulations (collision rate, binary shrinking, r_{avoid})

Thank you!

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