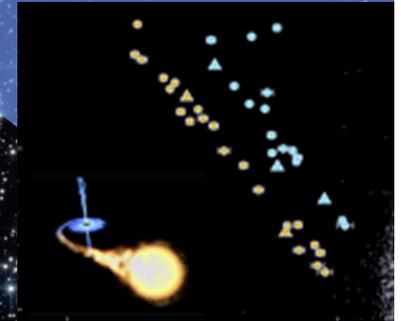




The Ecology of Blue Straggler Stars

ESO, Santiago, Chile
5–9 November 2012



Probing the dynamical evolution of stellar aggregates with BSS radial distribution

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Physics & Astronomy Department – University of Bologna
(Italy)



Cosmic-Lab

www.cosmic-lab.eu



erc



- ✦ 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

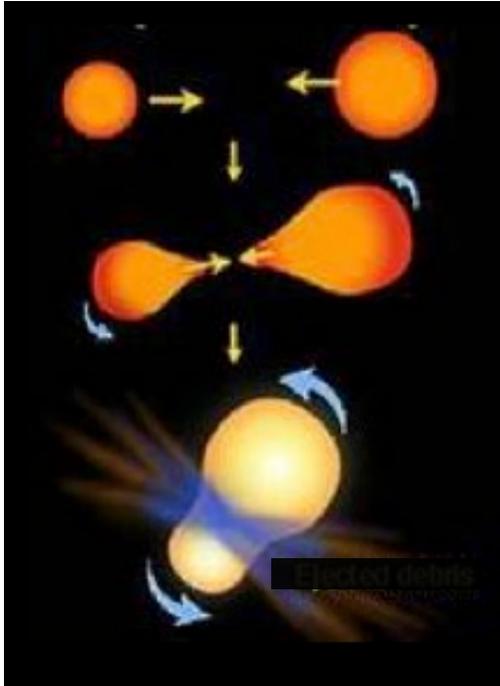
Intermediate-mass Black Holes

} as probe-particles

BSS as dynamical probes: why?

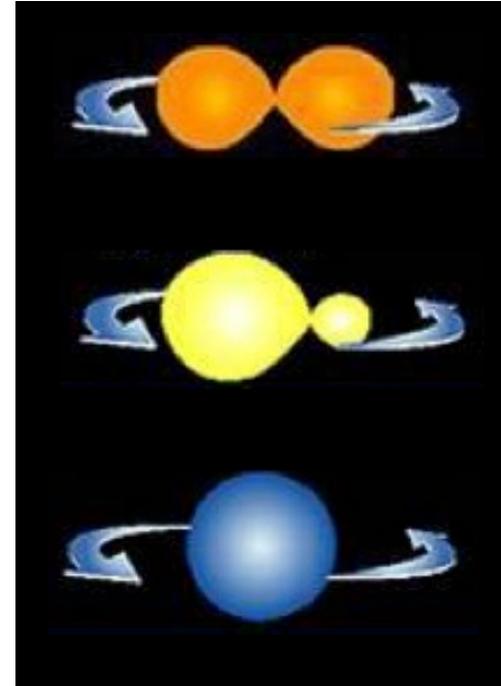
1)

COLLISIONAL BSS



depend on **collision** rate

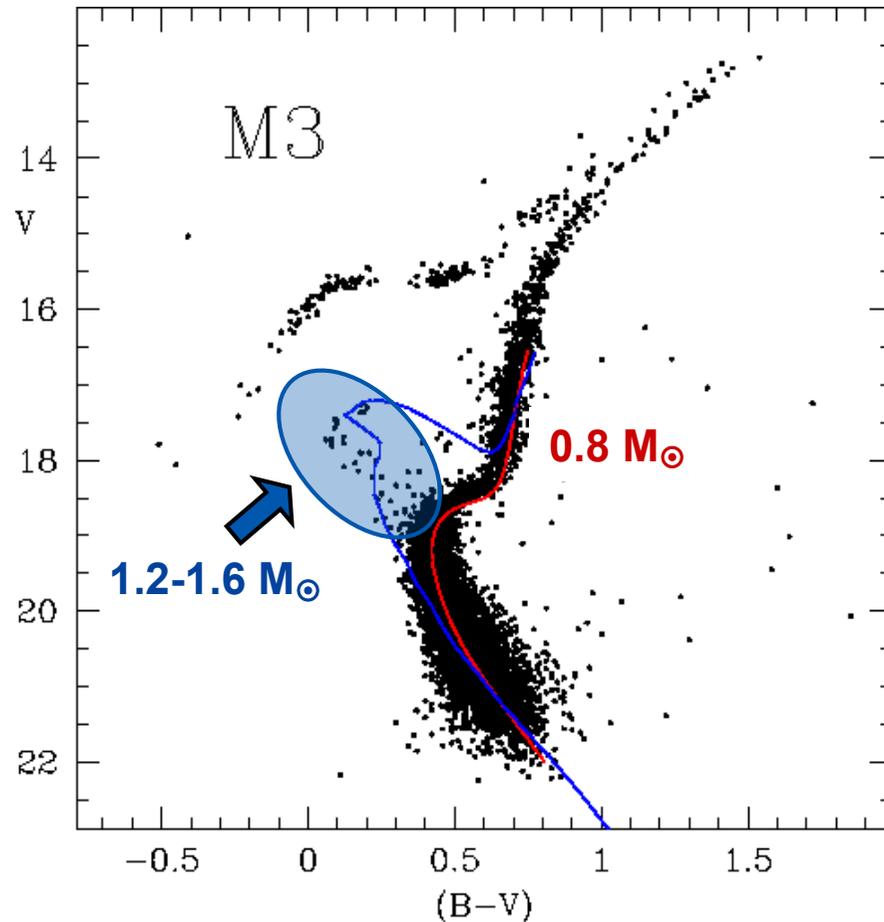
MASS-TRANSFER BSS



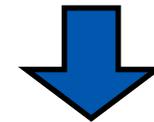
depend on shrinking of binaries
due to **dynamical interactions**
(and stellar evolution)

BSS as dynamical probes: why?

2)



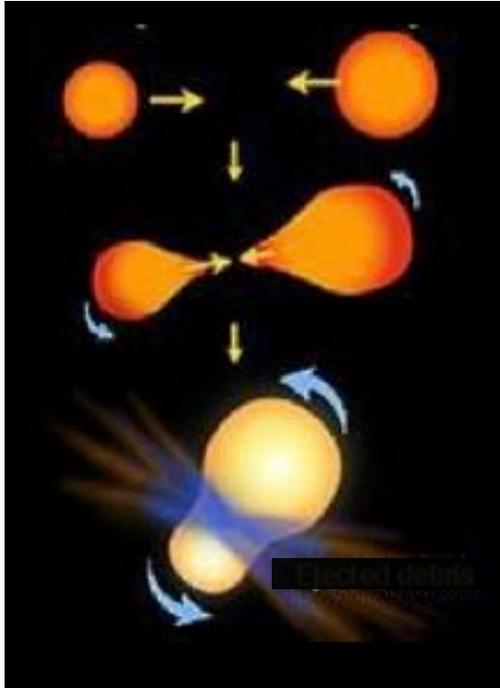
- BSS (both COL- & MT-) **more massive** than the average
- progenitors of MT-BSS (binaries) **more massive** than the average



suffer from the effects of **dynamical friction**

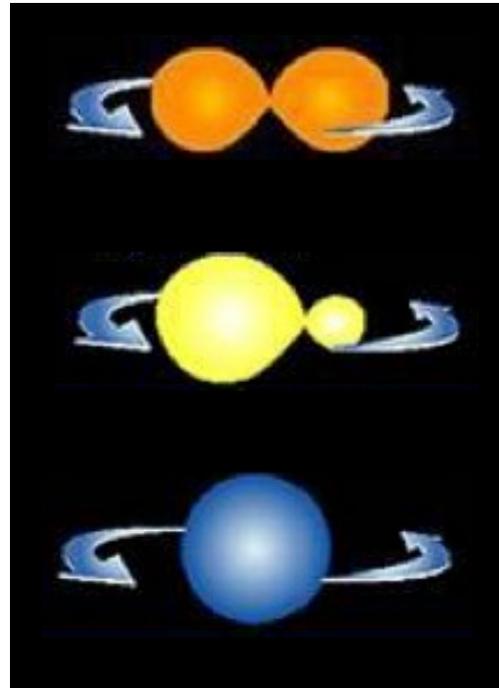
BSS as dynamical probes: why?

collisional BSS



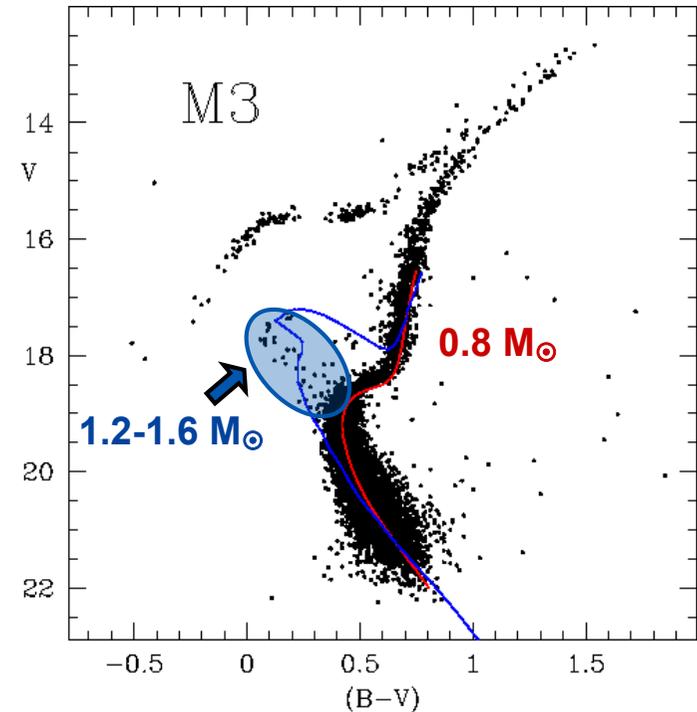
collisions

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)**

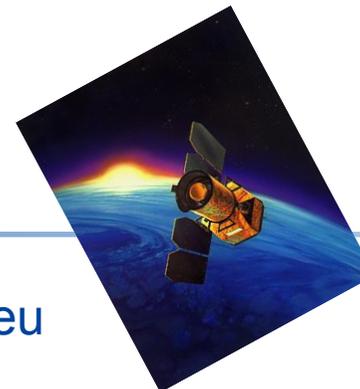


HST (WFPC2, ACS, WFC3)

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



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

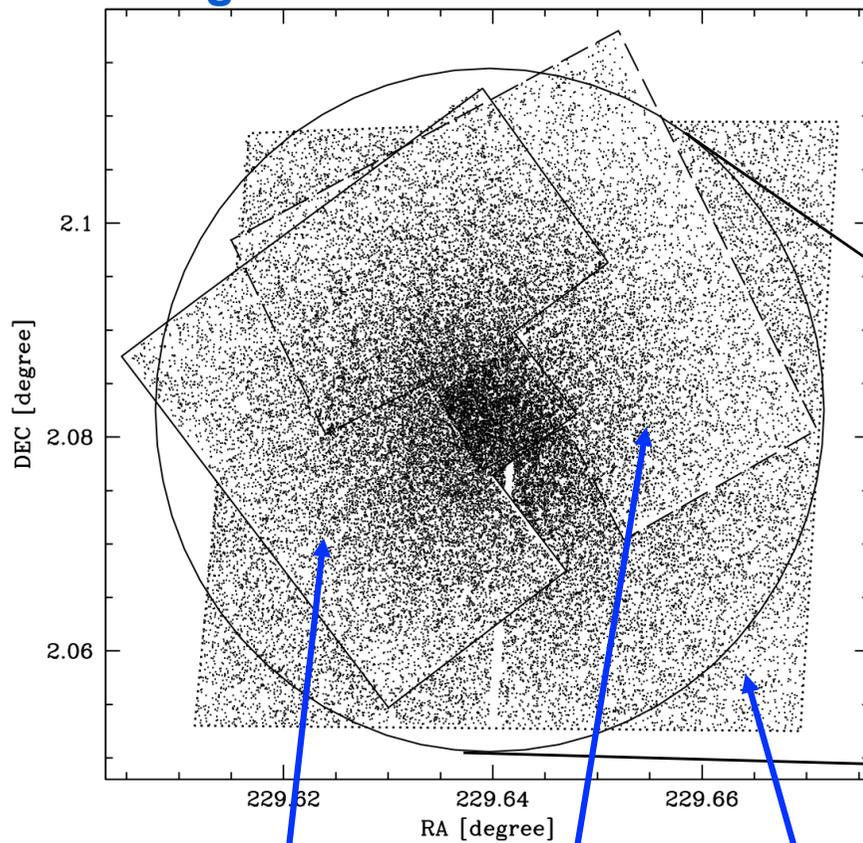


Data-set

M5 (NGC5904)



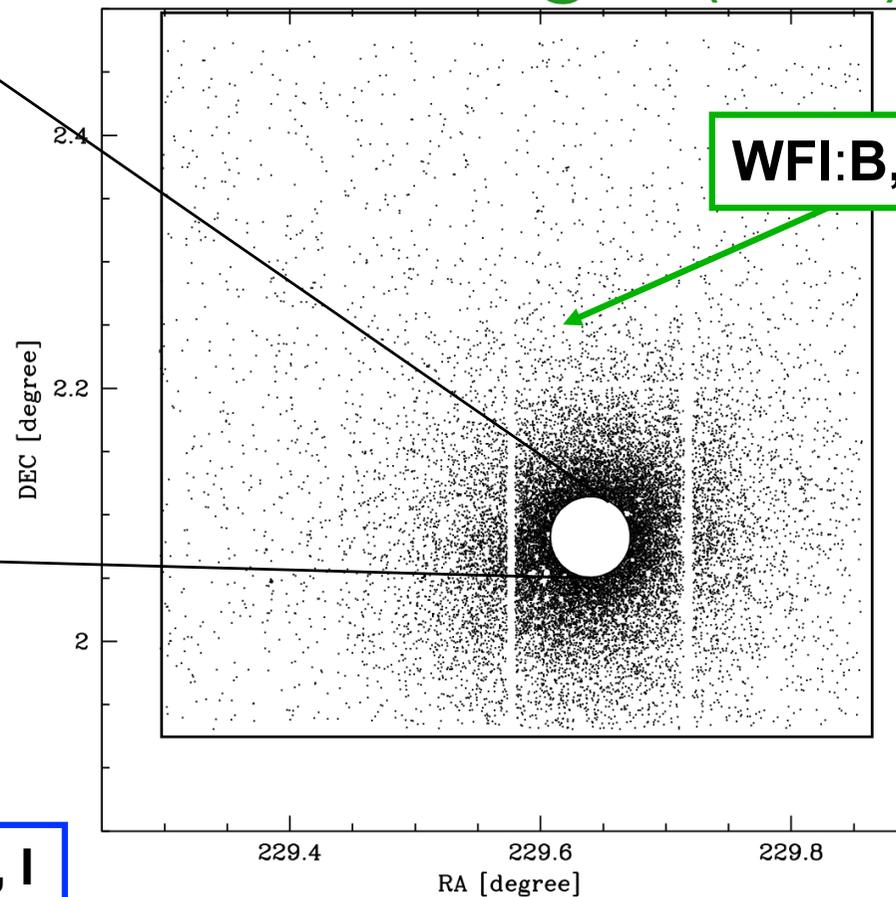
High-Res: HST/WFPC2+ACS



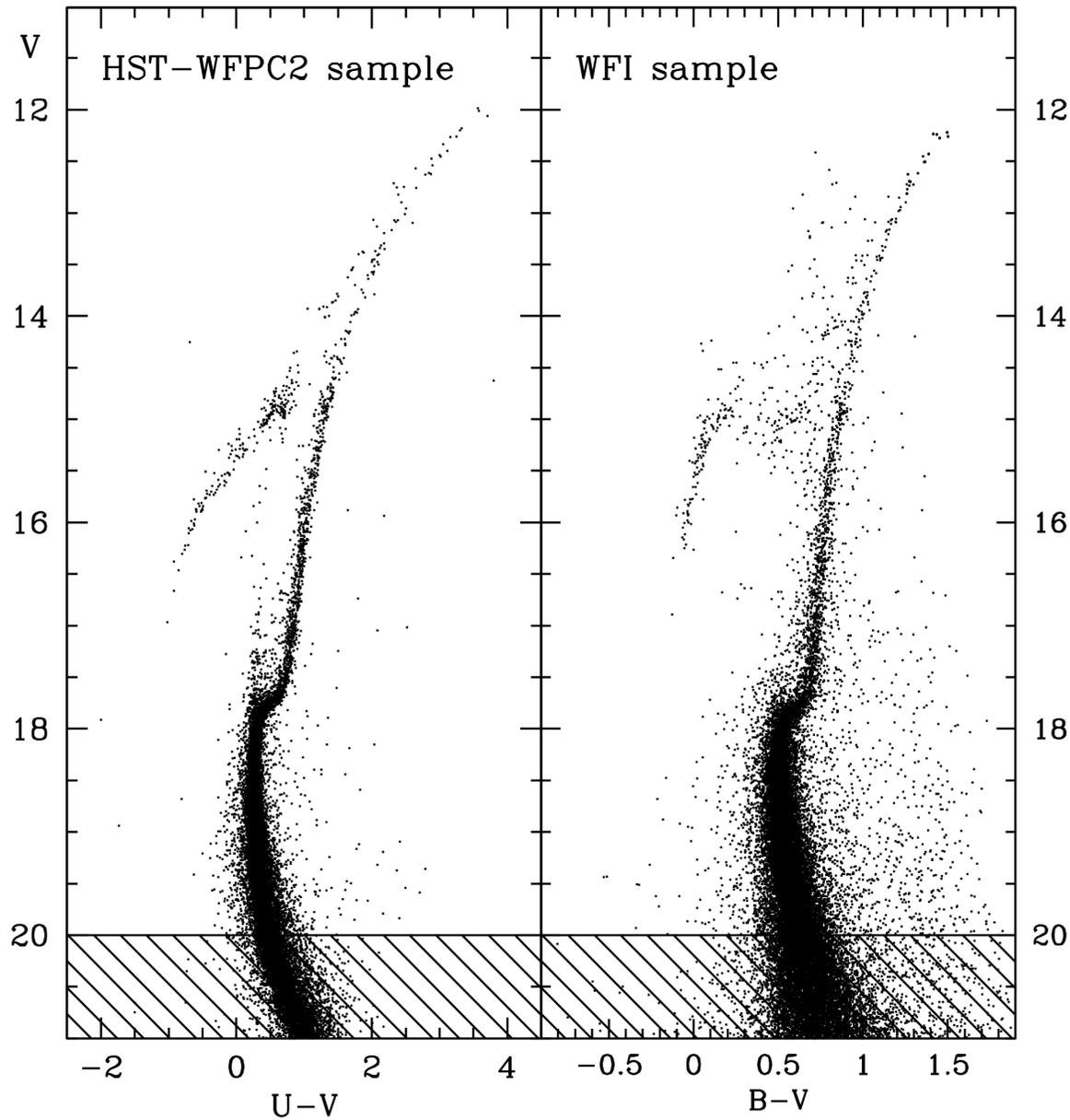
WFPC2: mid-UV (F255W), U, B, V

ACS: B, V, I

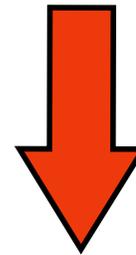
Wide-Field: WFI@ESO (34'x33')



WFI: B, V

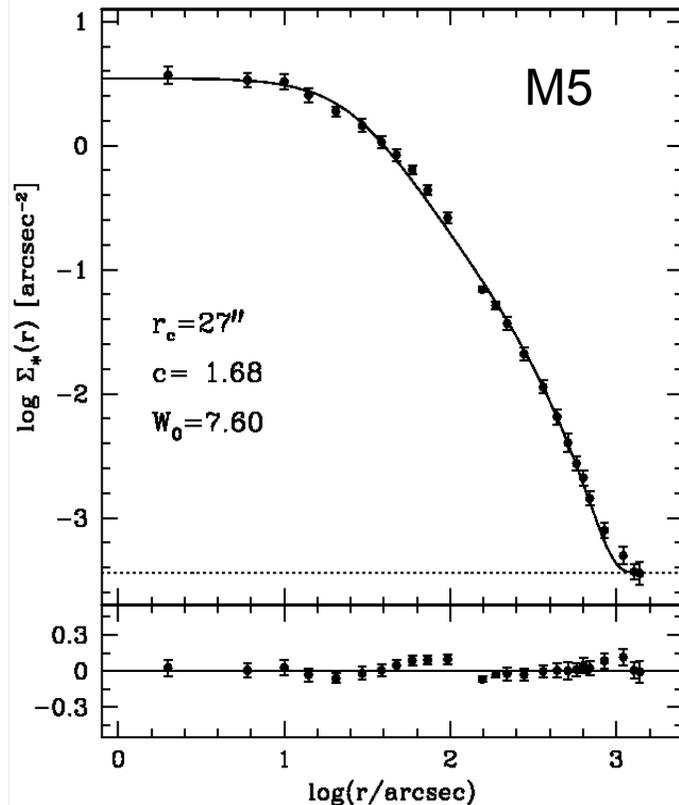


**large & complete
samples of
resolved stars
all over the entire
cluster extension**



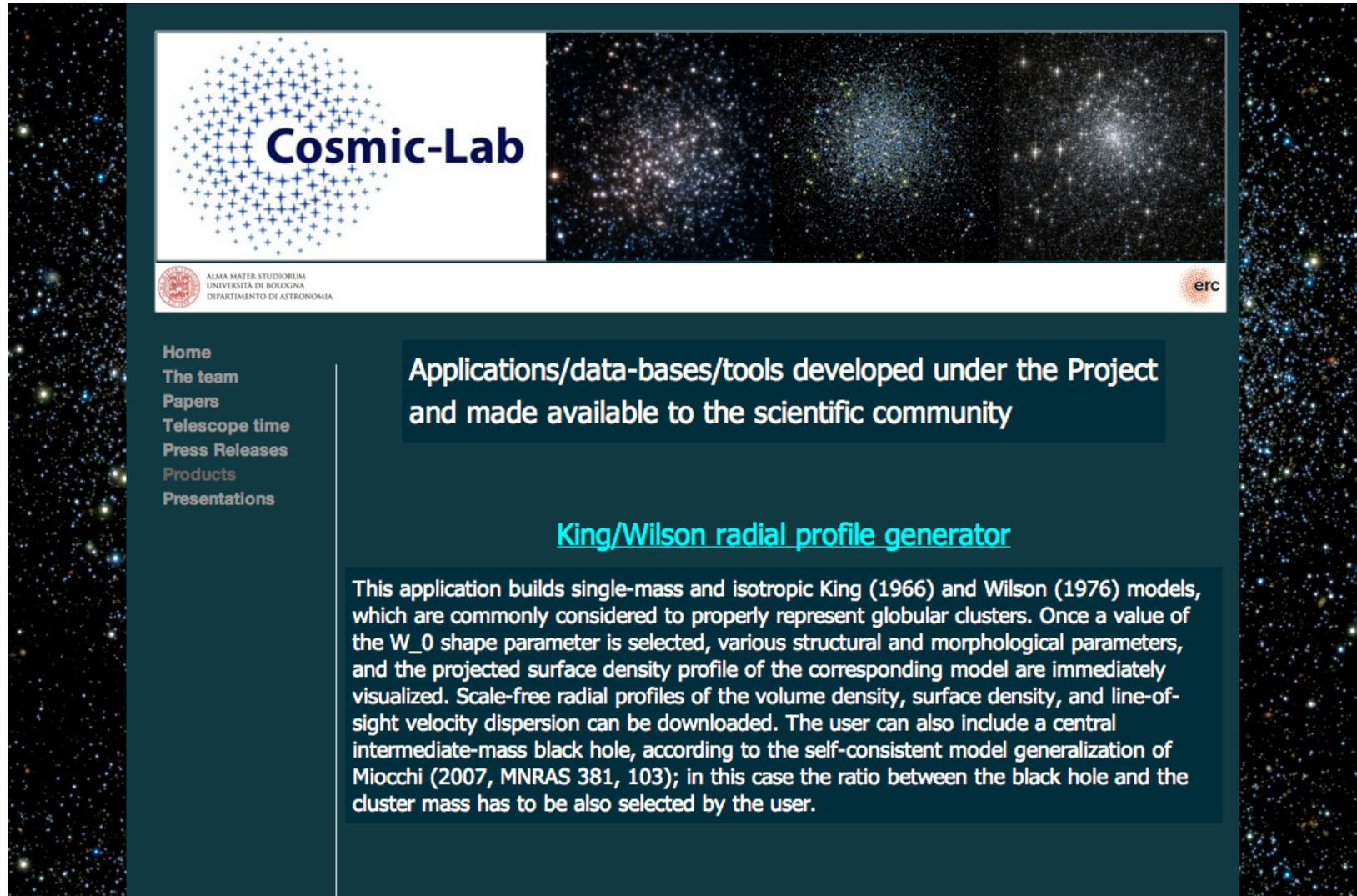
Centre & density profile from resolved star counts

- ✓ **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



The screenshot shows the Cosmic-Lab website interface. At the top left is the Cosmic-Lab logo, a circular pattern of blue stars. To its right is a large image of a star cluster. Below the logo is the text 'ALMA MATER STUDIORUM UNIVERSITA DI BOLOGNA DIPARTIMENTO DI ASTRONOMIA' and the ERC logo. A navigation menu on the left lists: Home, The team, Papers, Telescope time, Press Releases, Products, and Presentations. The main content area features a dark blue box with the text 'Applications/data-bases/tools developed under the Project and made available to the scientific community'. Below this is a link for 'King/Wilson radial profile generator' and a detailed description of the application's capabilities.

Cosmic-Lab

ALMA MATER STUDIORUM
UNIVERSITA DI BOLOGNA
DIPARTIMENTO DI ASTRONOMIA

erc

Home
The team
Papers
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Products
Presentations

Applications/data-bases/tools developed under the Project
and made available to the scientific community

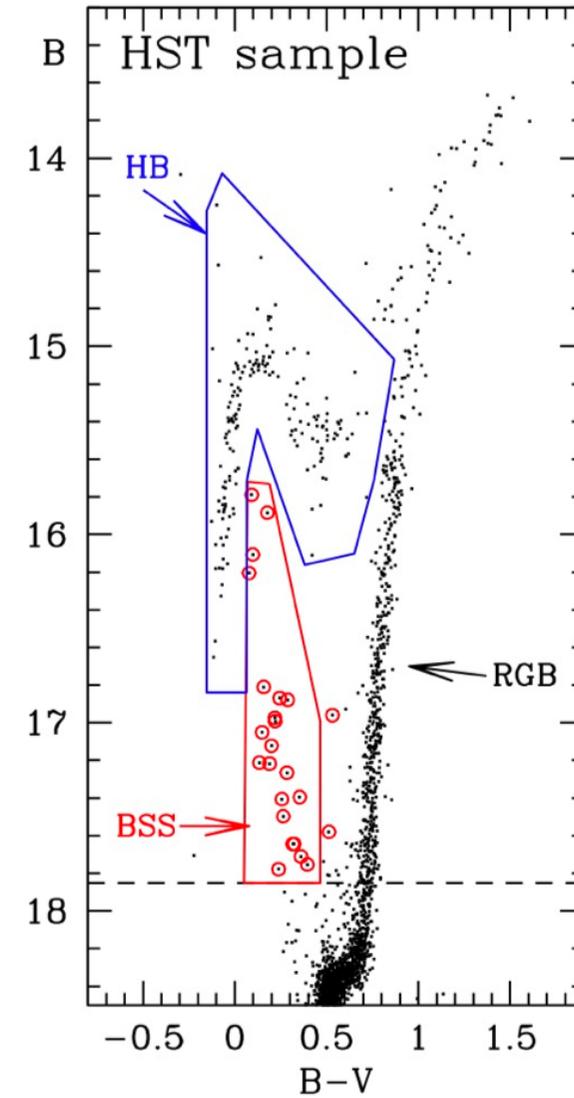
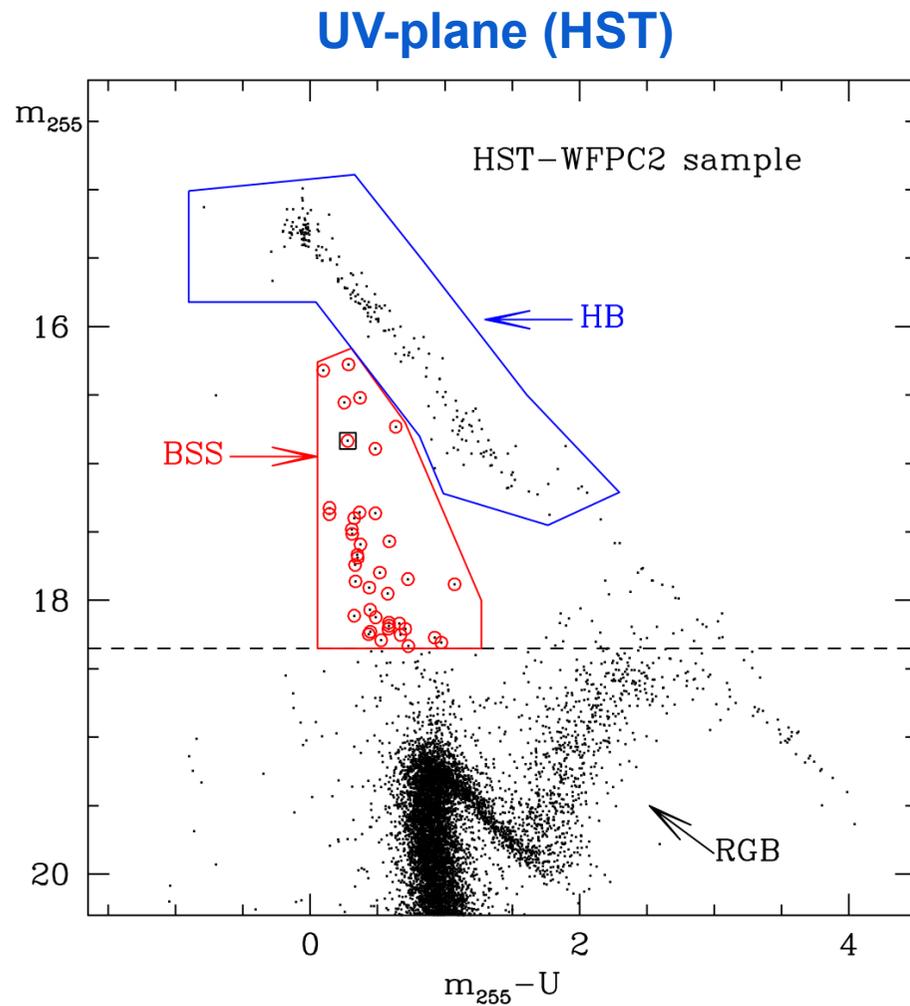
[King/Wilson radial profile generator](#)

This application builds single-mass and isotropic King (1966) and Wilson (1976) models, which are commonly considered to properly represent globular clusters. Once a value of the W_0 shape parameter is selected, various structural and morphological parameters, and the projected surface density profile of the corresponding model are immediately visualized. Scale-free radial profiles of the volume density, surface density, and line-of-sight velocity dispersion can be downloaded. The user can also include a central intermediate-mass black hole, according to the self-consistent model generalization of Miocchi (2007, MNRAS 381, 103); in this case the ratio between the black hole and the cluster mass has to be also selected by the user.

BSS selection

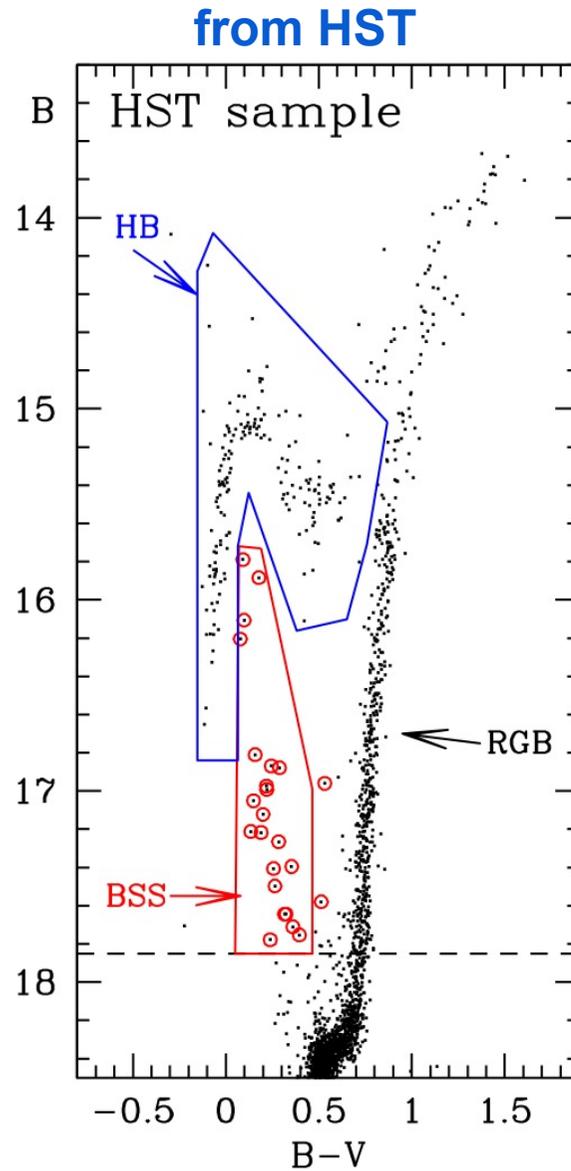
M5 (NGC5904)

optical plane (HST)



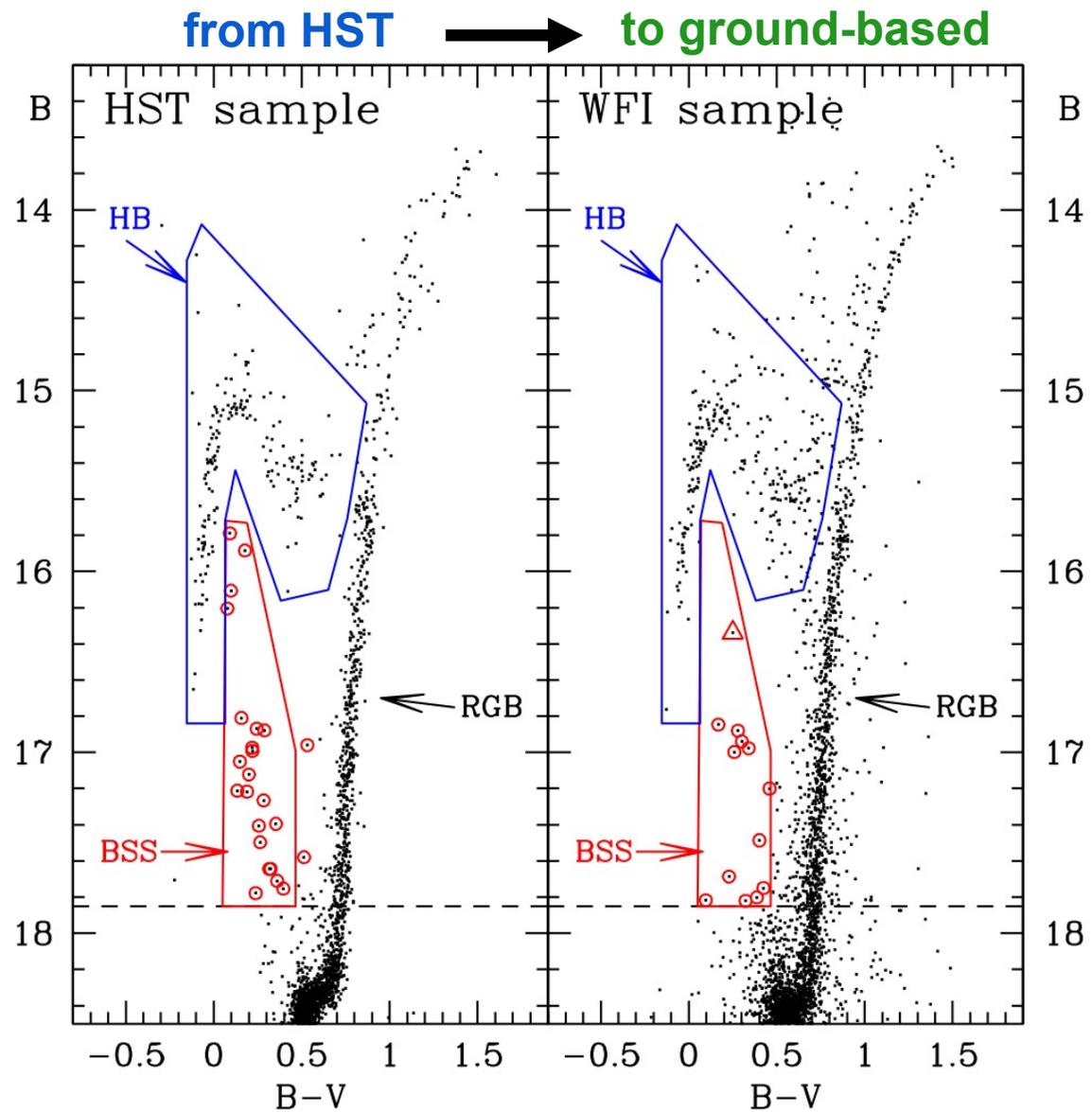
BSS selection

M5 (NGC5904)



BSS selection

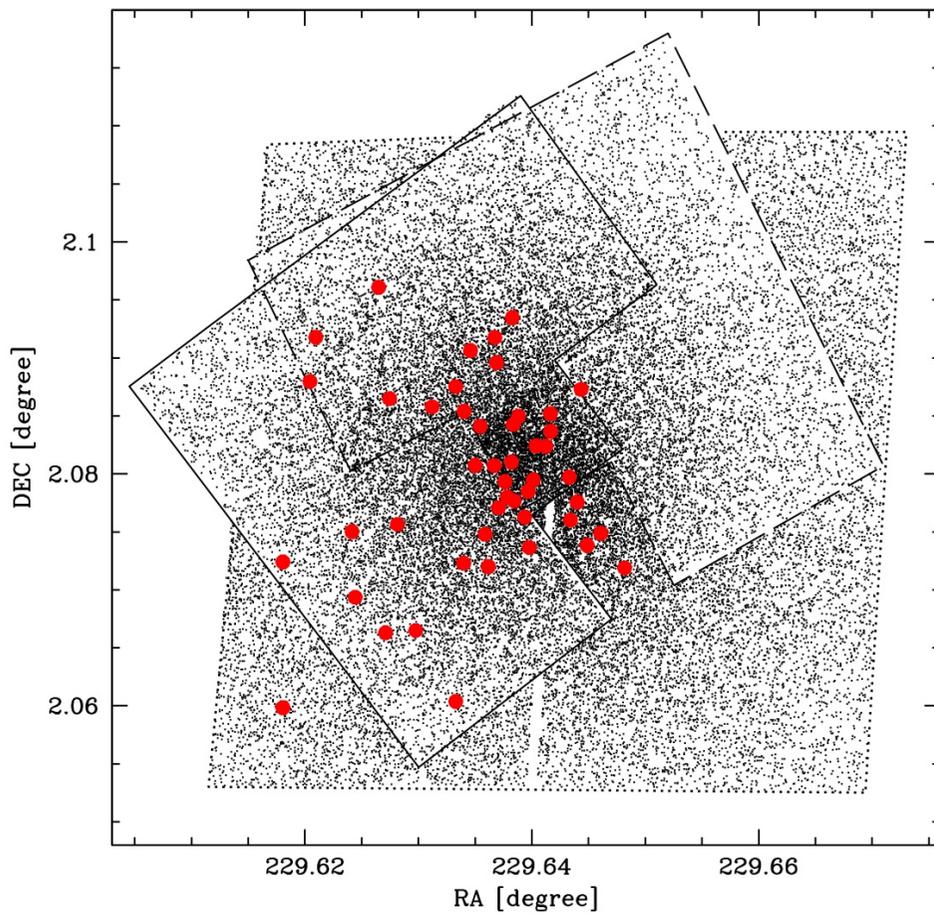
M5 (NGC5904)



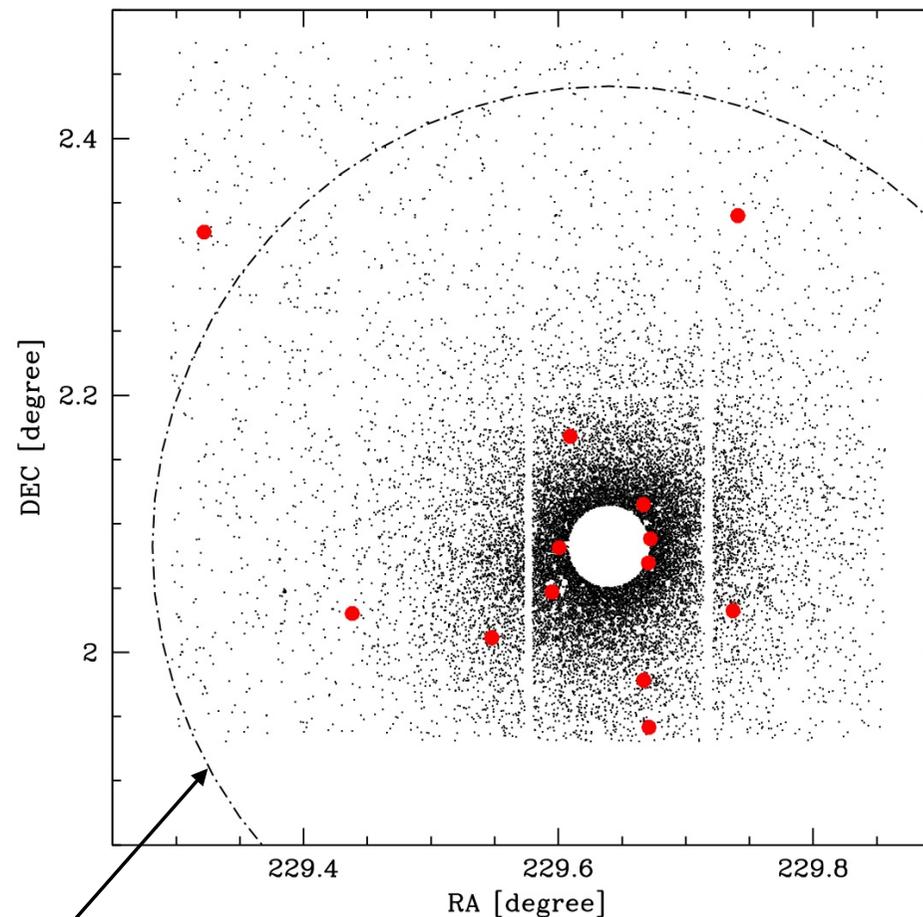
BSS radial distribution

M5 (NGC5904)

High-Res WFPC2+ACS HST



Wide-Field WFI@ESO



$r_t = 21.5$

cumulative radial distribution

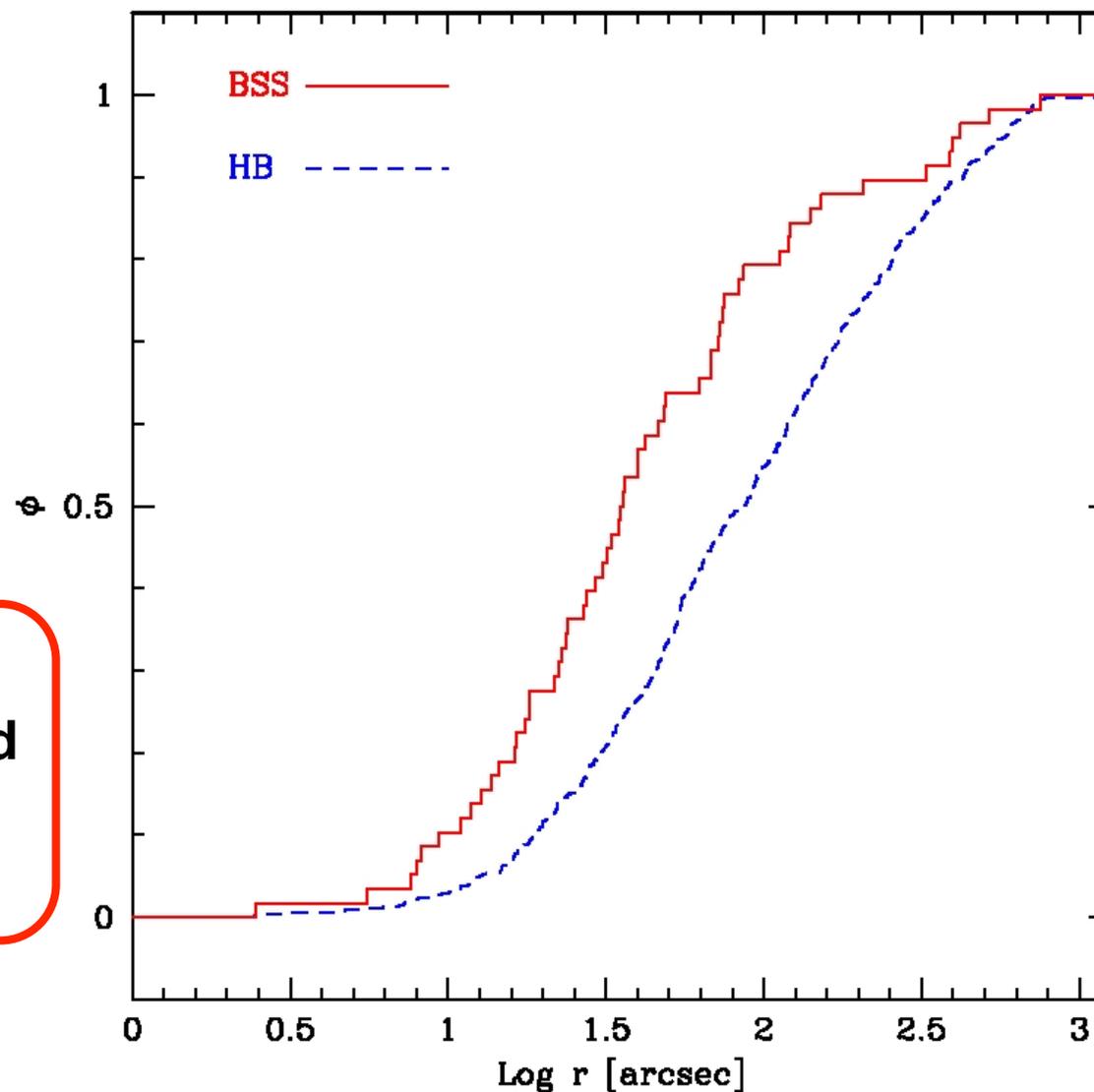
M5 (NGC5904)

KS-test:

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



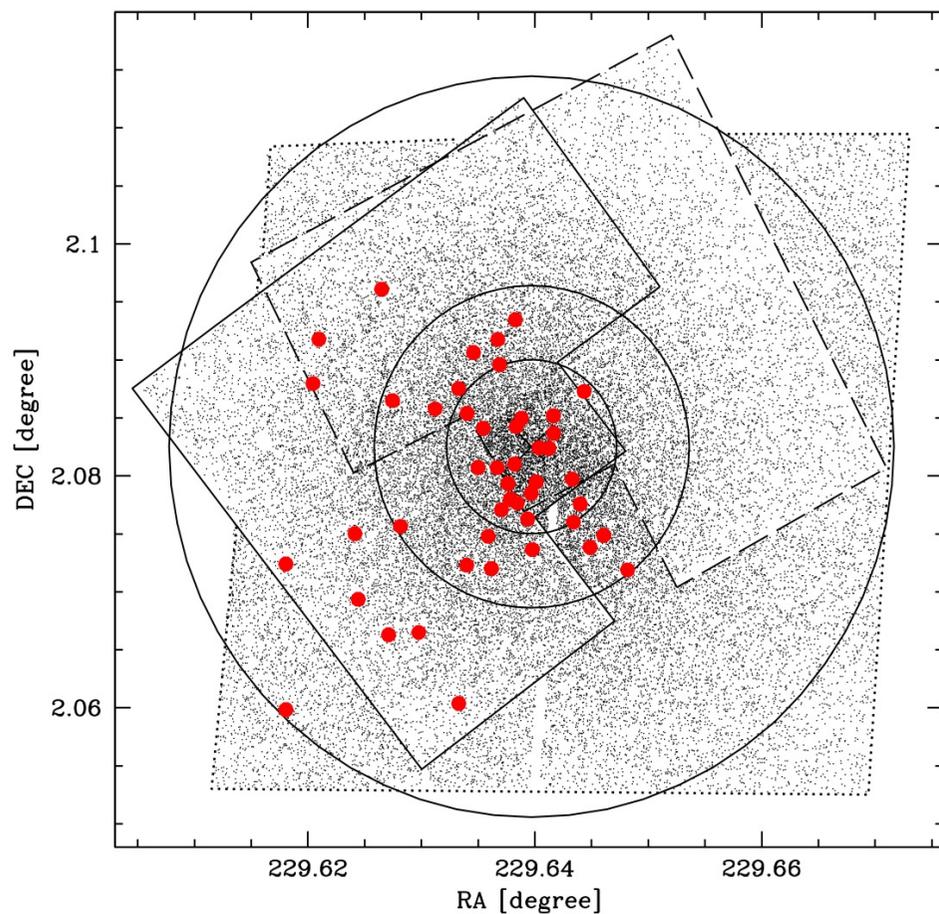
**BSS are
more centrally concentrated
than HB
at more than 4σ level**



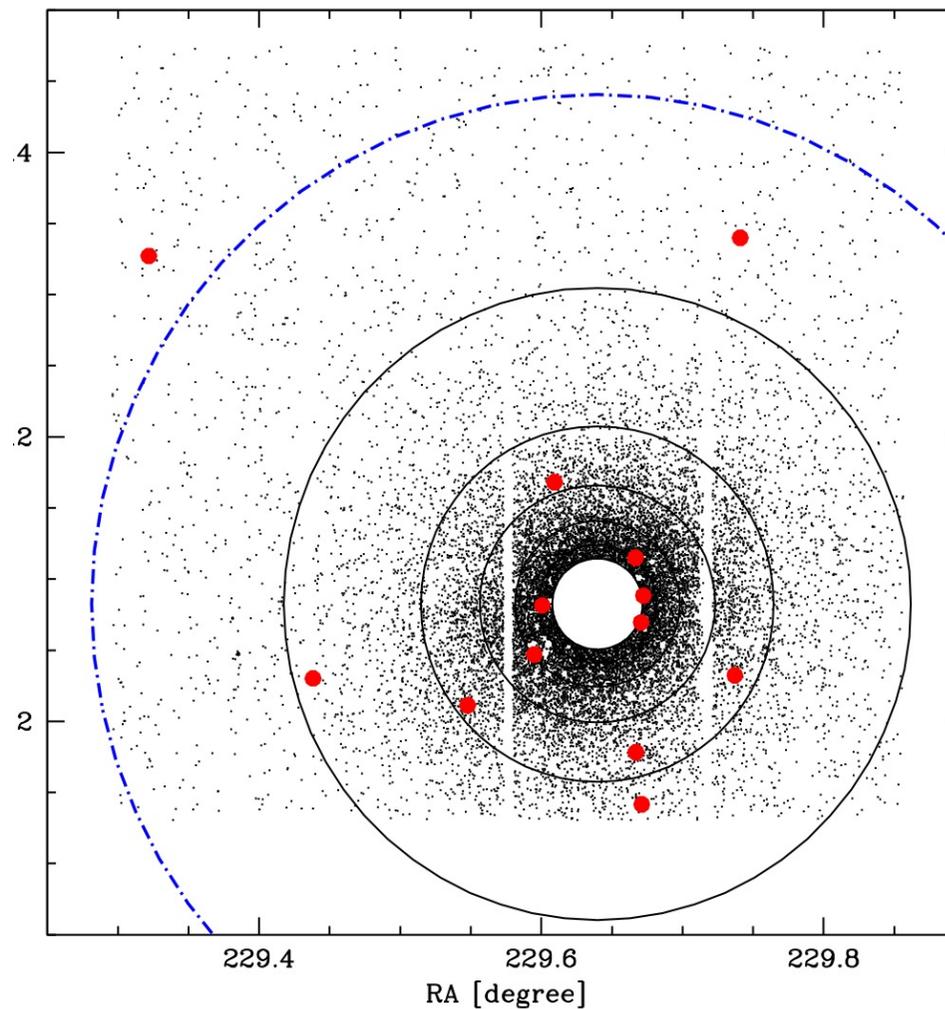
BSS radial distribution

M5 (NGC5904)

High-Res WFPC2+ACS HST

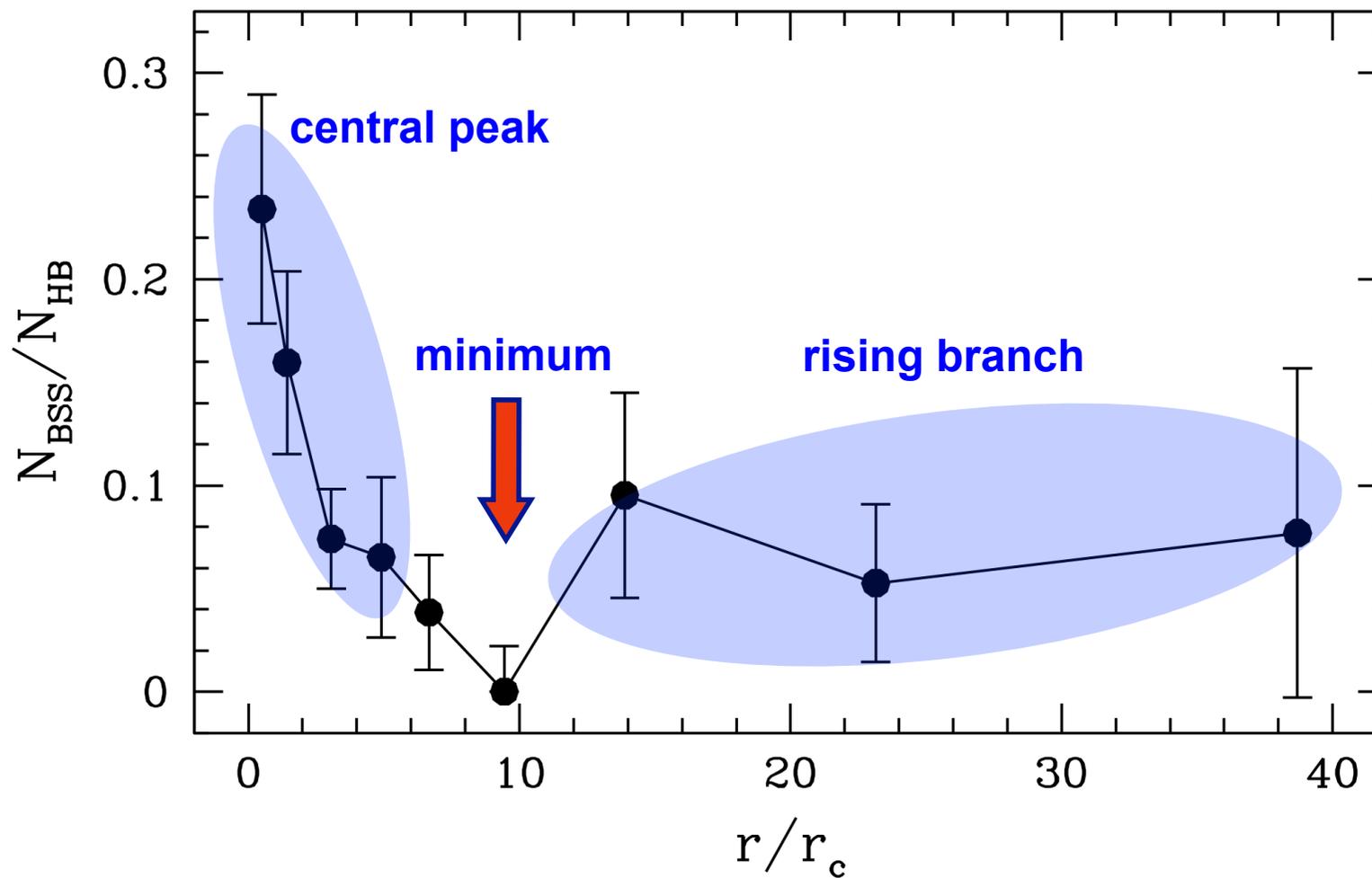


Wide-Field WFI@ESO



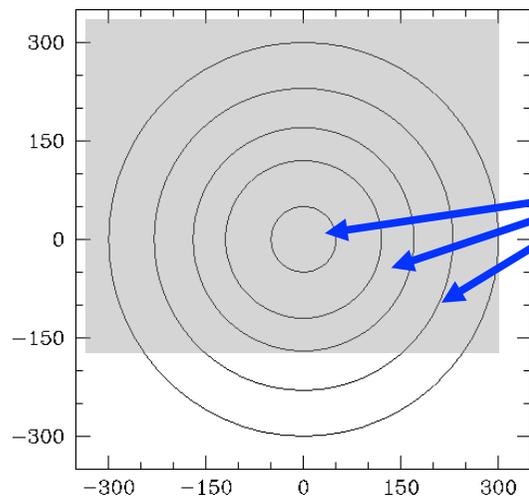
Specific frequency

M5 (NGC5904)



Doubled normalized ratio

M5 (NGC5904)



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

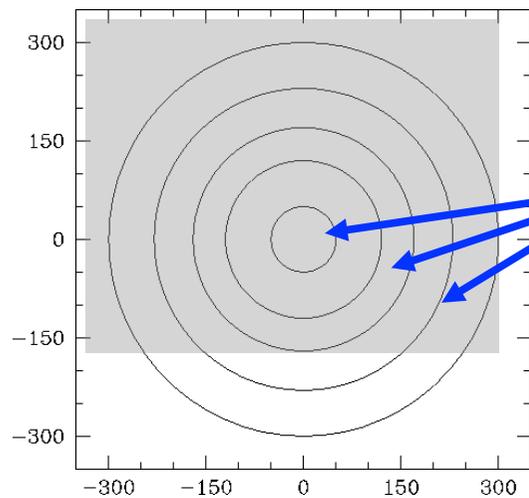


$R_{\text{pop}}=1$ for any non-segregated population

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

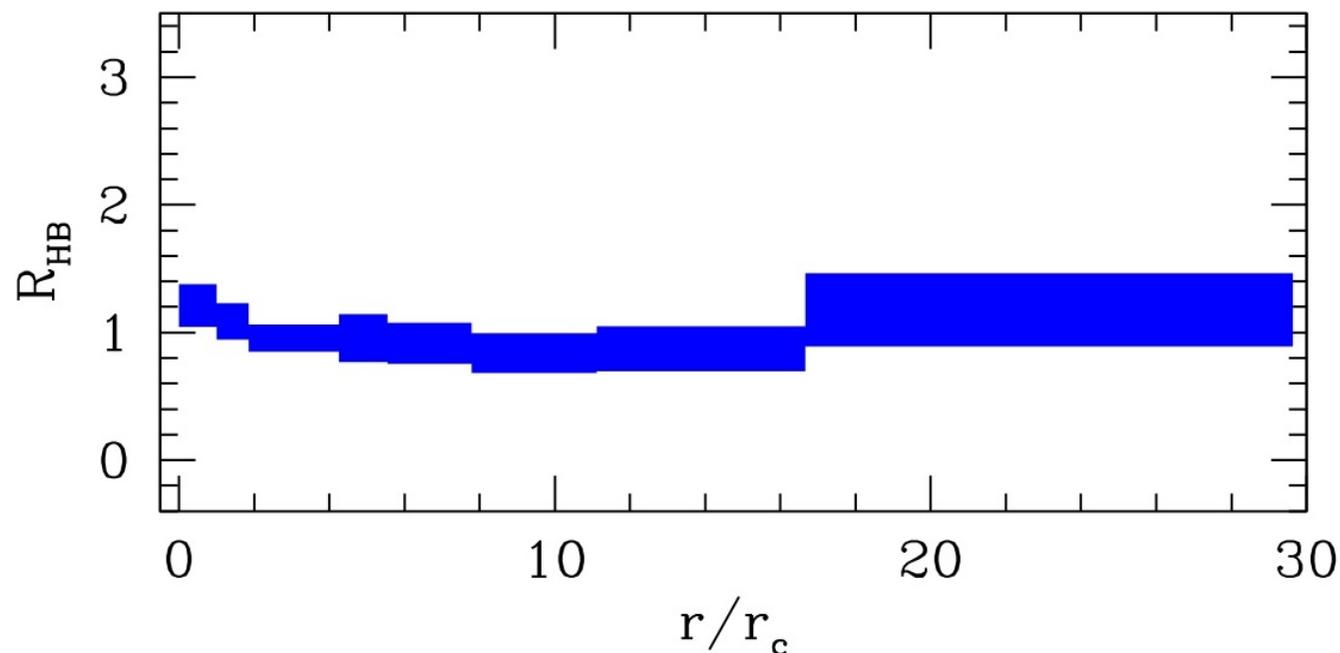
Doubled normalized ratio

M5 (NGC5904)



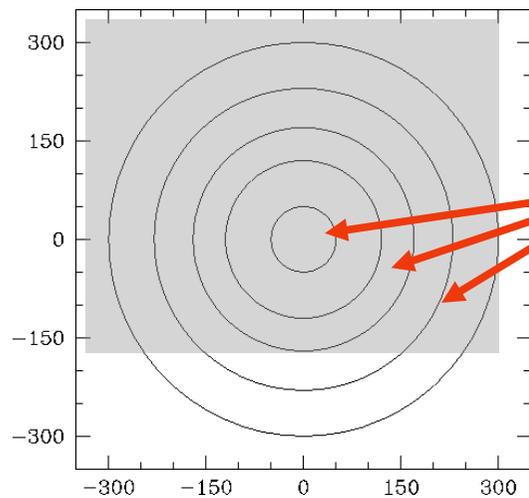
$$R_{\text{HB}} = \frac{N_{\text{HB}}/N_{\text{HB,TOT}}}{L_{\text{samp}}/L_{\text{TOT}}}$$

**HB stars
NOT
segregated
in the centre**



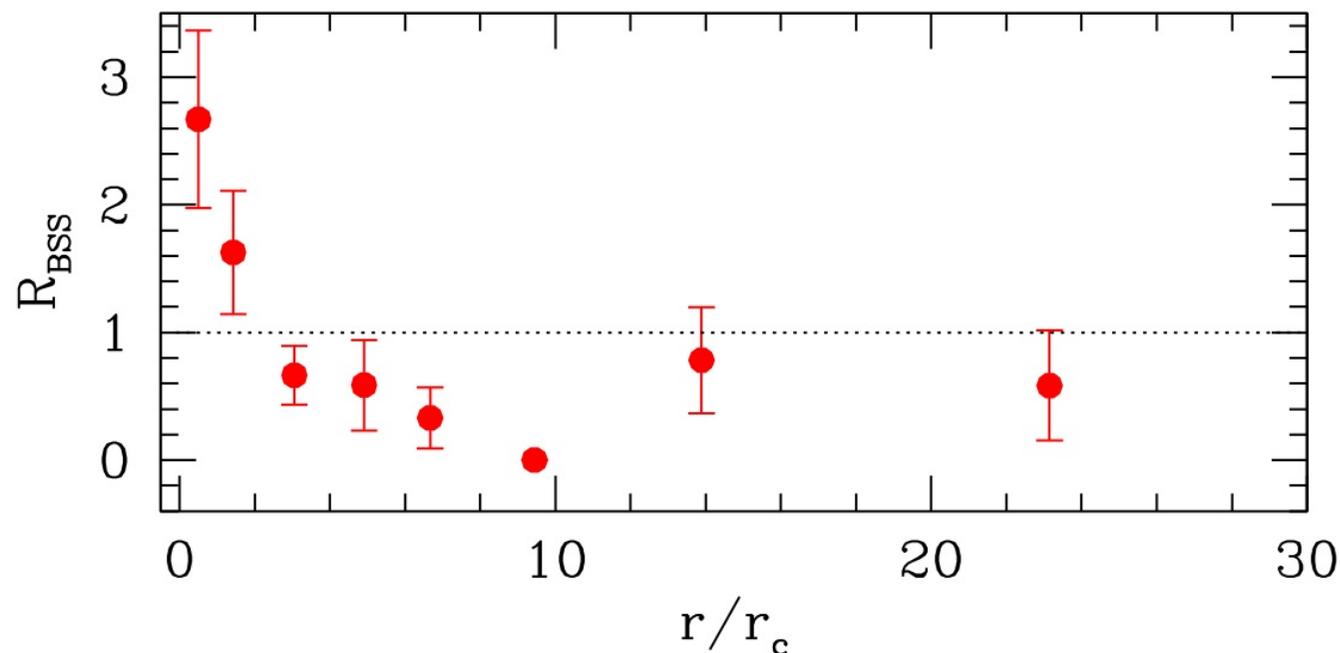
Doubled normalized ratio

M5 (NGC5904)

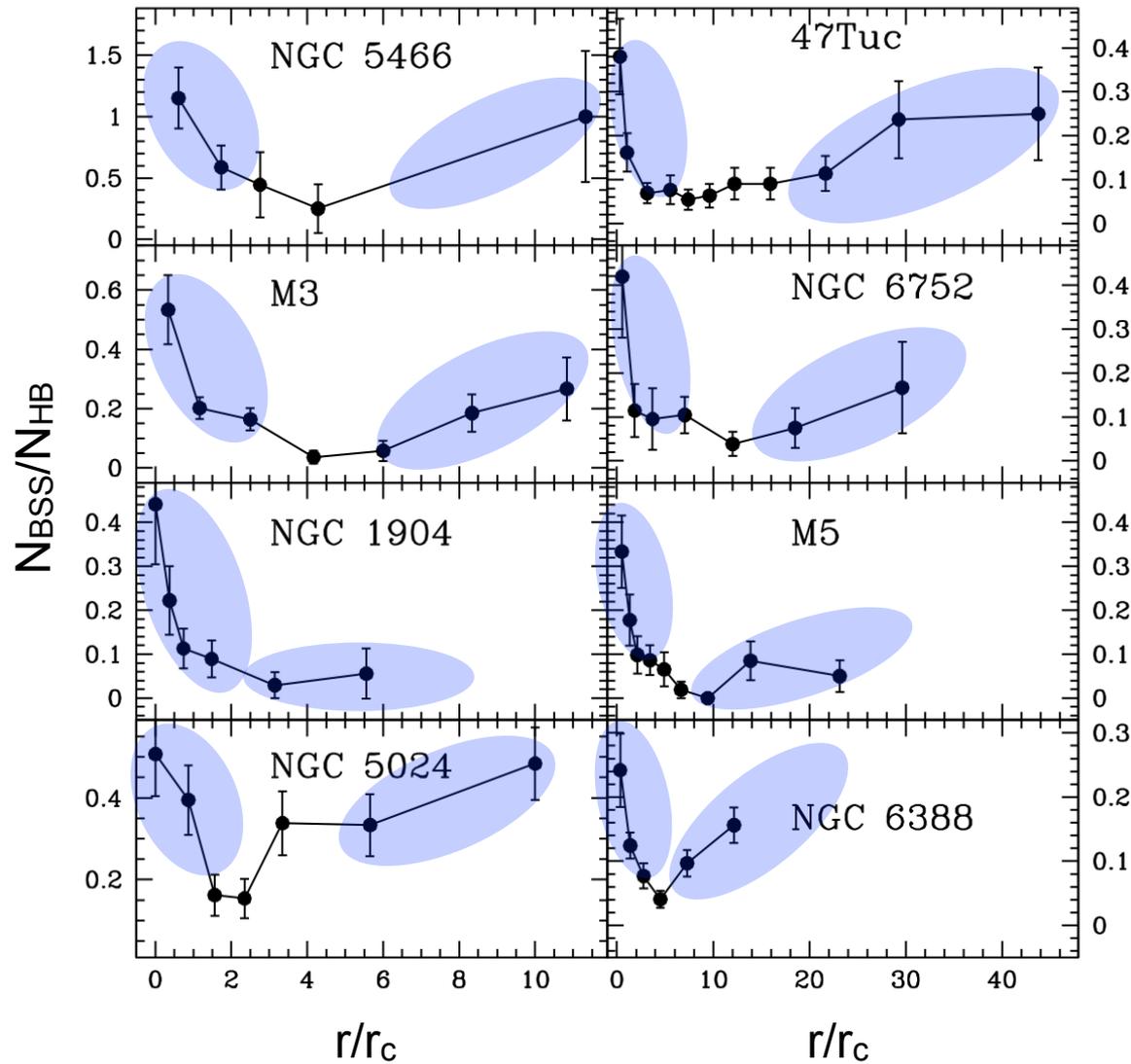


$$R_{\text{BSS}} = \frac{N_{\text{BSS}}/N_{\text{BSS,TOT}}}{L_{\text{samp}}/L_{\text{TOT}}}$$

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);

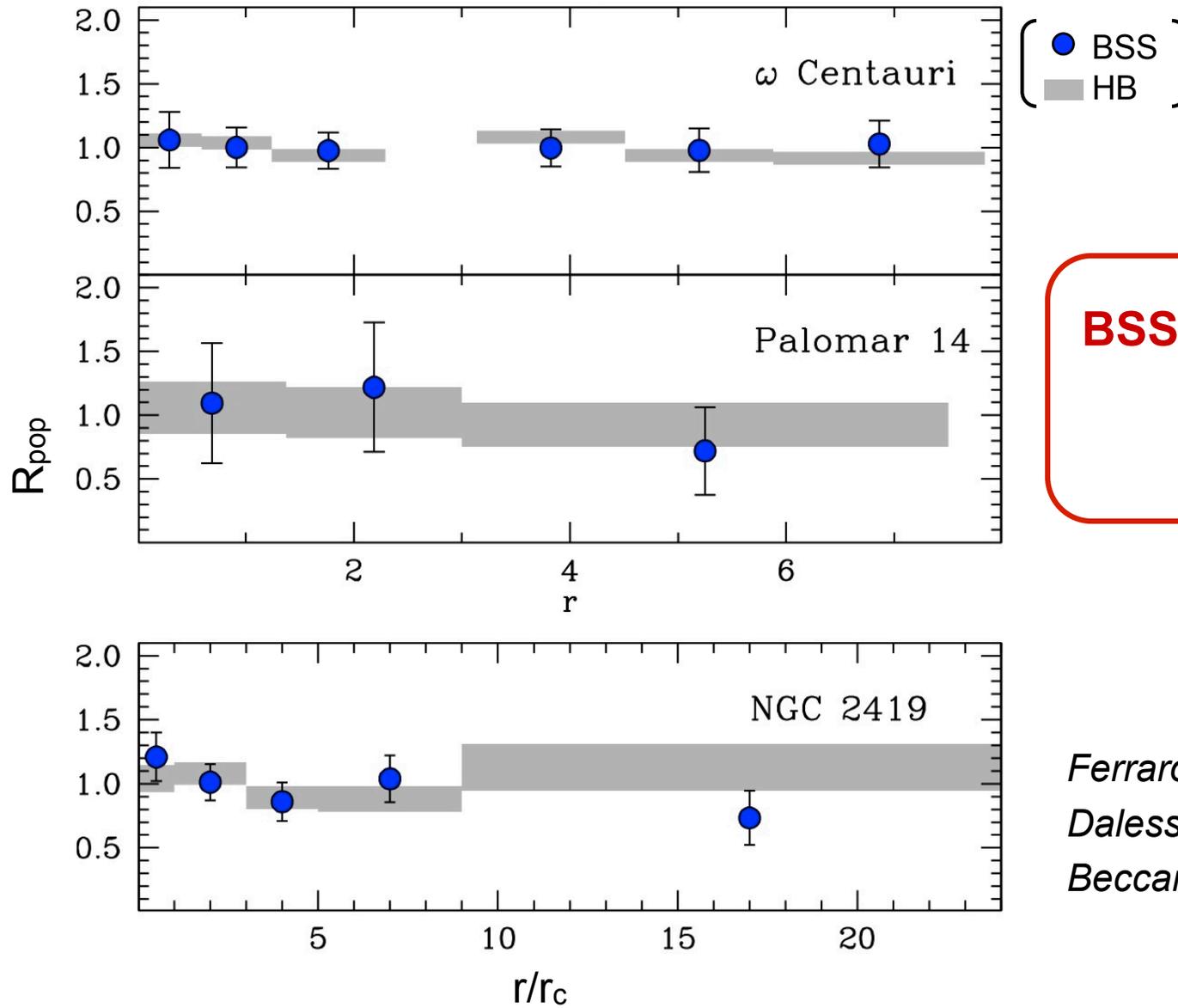
Beccari et al. (08, 09);

Contreras Ramos et al. (12);

Sanna et al. (12)

...

Results (2)



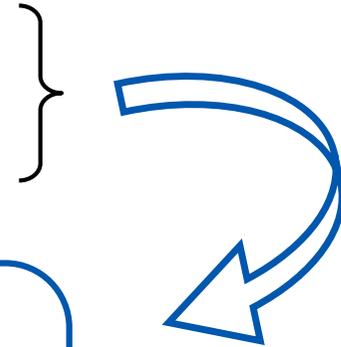
**BSS radial distribution
FLAT
in 3 cases**

*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 (\rightarrow dynamical friction)
- flat BSS radial distribution in 3 cases

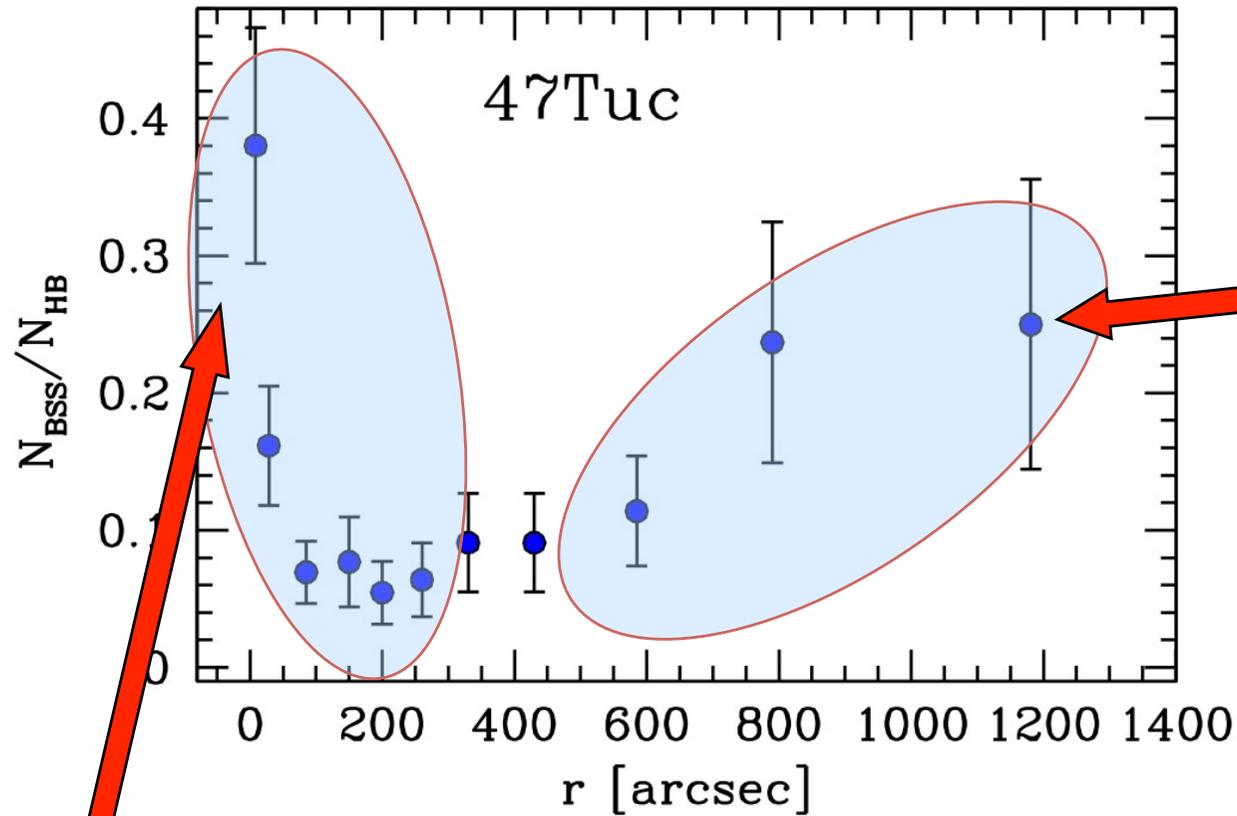


**ω Cen, Pal14, NGC2419
are not mass-segregated yet
(even in the central regions)**

$\left(\begin{array}{l} \omega\text{Cen: } t_{rc} \sim t_{AGE} \\ \text{Pal14: } t_{rc} \sim 20 \text{ Gyr} \\ \text{NGC2419: } t_{rc} \sim 18 \text{ Gyr} \end{array} \right)$

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:**

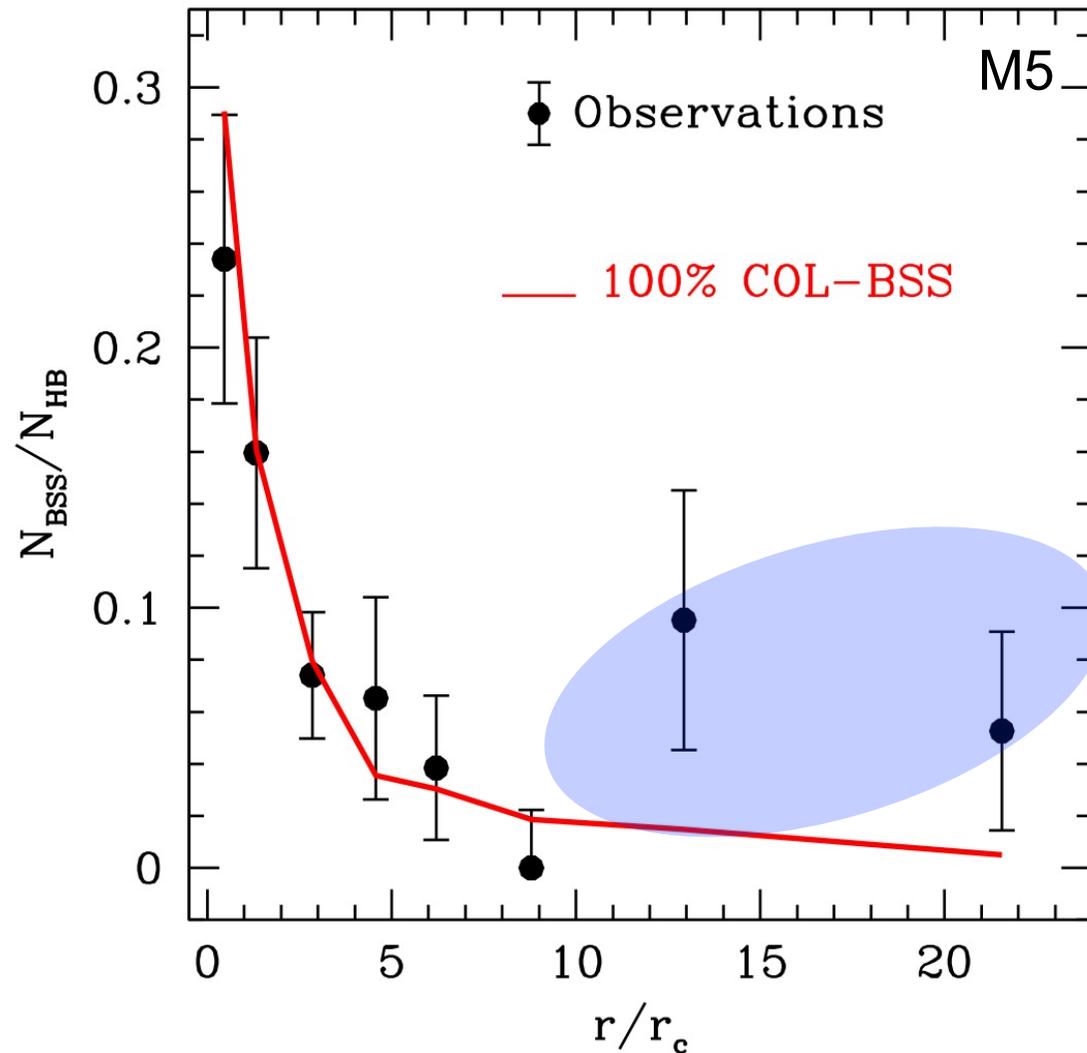
“COL-BSS”: generated within r_c , with natal kick velocity

“MT-BSS”: generated from primordial binaries at $r \gg r_c$, with no natal kick

- **Dynamical evolution due to:**

dynamical friction and distant encounters

Monte-Carlo simulations of BSS evolution

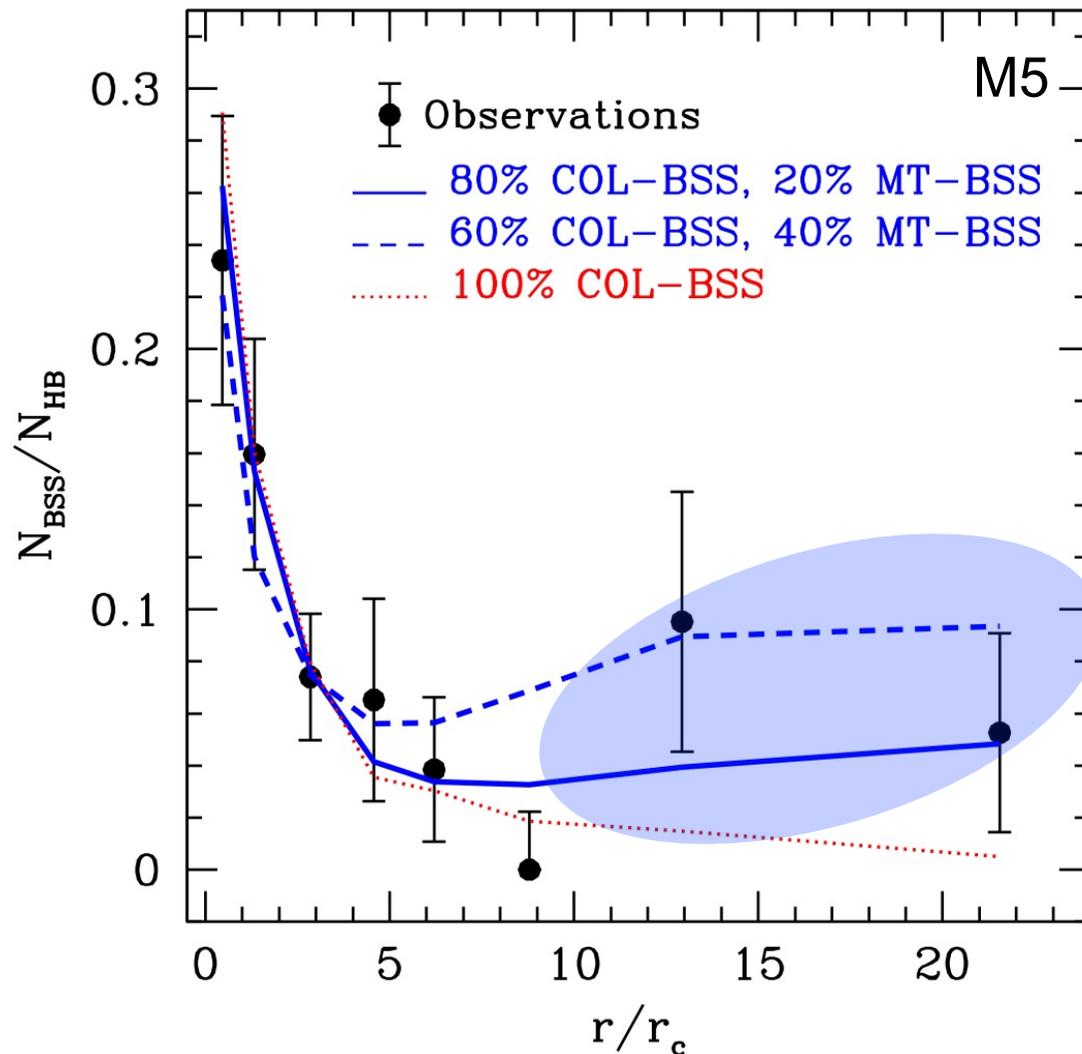


**COL-BSS kicked out
from the core
sink back in just 1-2 Gyr**

(*Mapelli et al. 2004, 2006*
Lanzoni et al. 2007a,b)

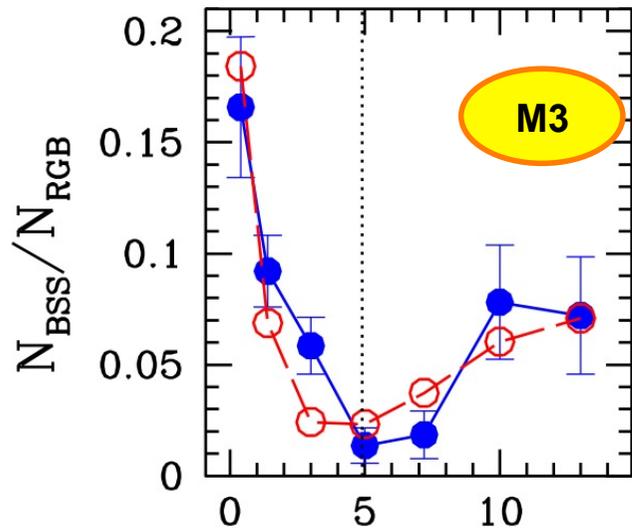
**COL-BSS only
CANNOT**
to reproduce the
external rising branch

Monte-Carlo simulations of BSS evolution



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

Monte-Carlo simulations of BSS evolution



● Observations:

M3:

Ferraro et al. (1993, 1997)

47 Tuc:

Ferraro et al. (2004)

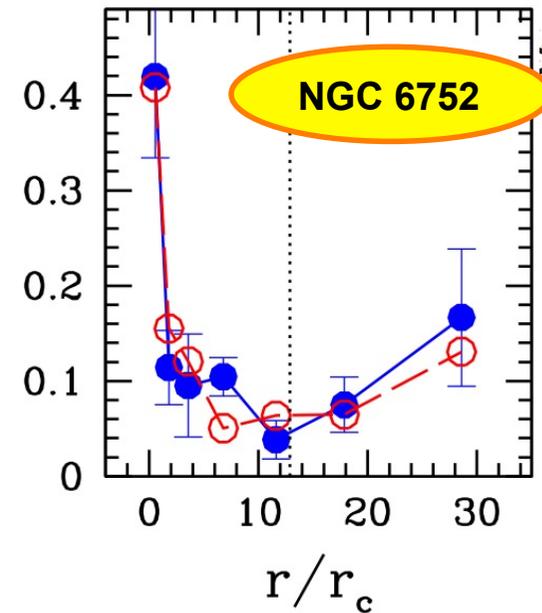
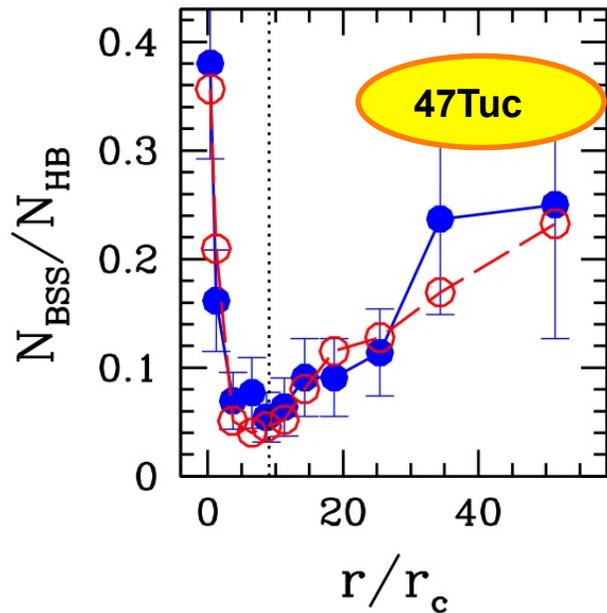
NGC 6752:

Sabbi et al. (2004)

○ Simulations:

Mapelli et al. (2004, 2006)

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 $M \sim M_{\text{BSS}}$ have sunk into the cluster centre in a time comparable to the cluster age because of dynamical friction:

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

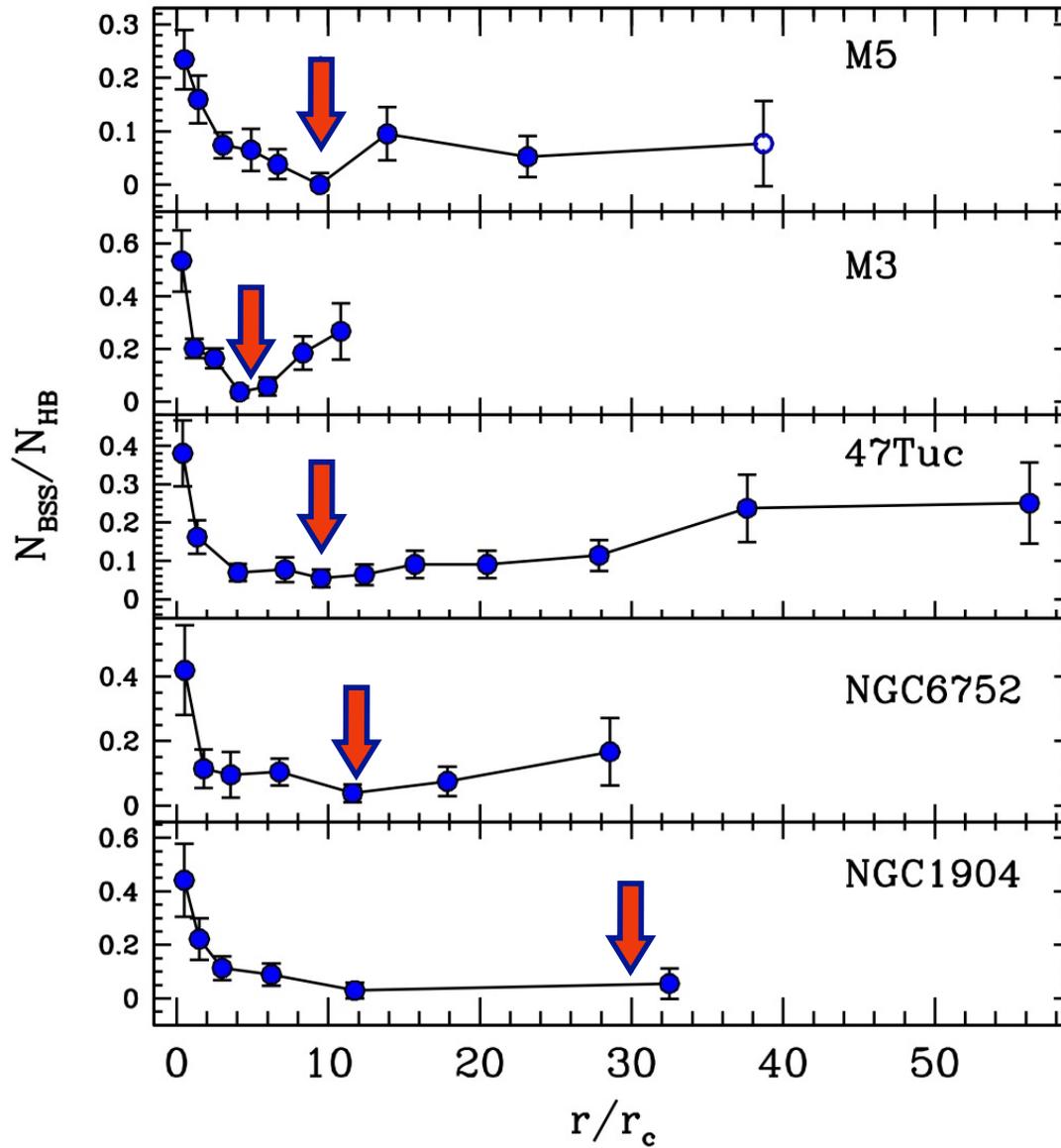
where:

$$M_{\text{BSS}} = 1.2 M_{\text{sol}}$$

$$t_{\text{AGE}} = 12 \text{ Gyr}$$

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