Stellar dynamics in globular clusters

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GGCs: a stellar laboratory

1) Stellar evolution

DEF: each star is treated as a single and isolated entity

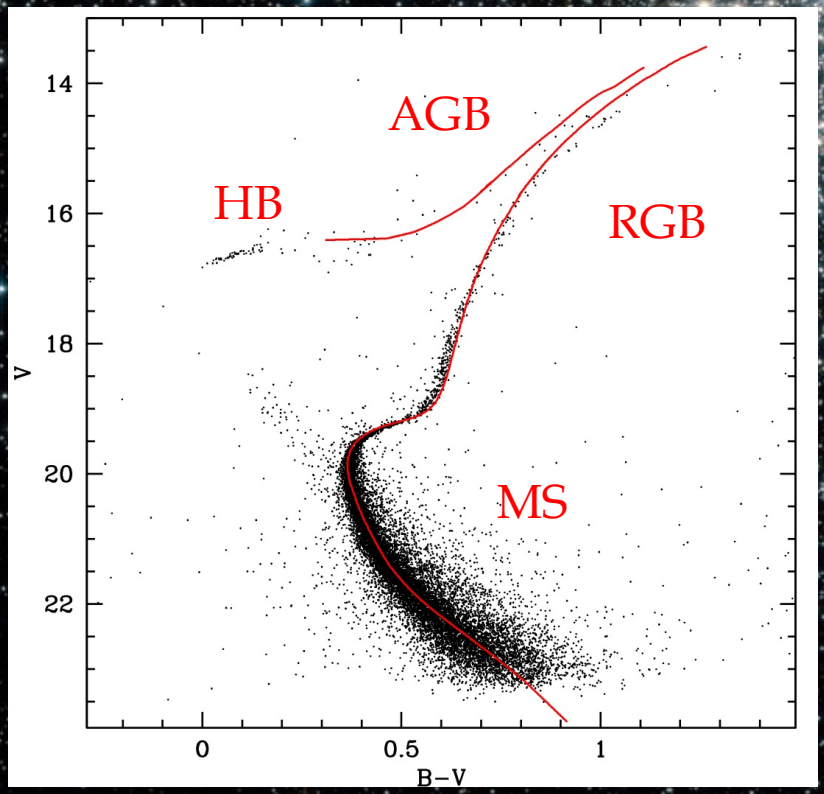
N.B. 10^5-6 stars in a GC!!!

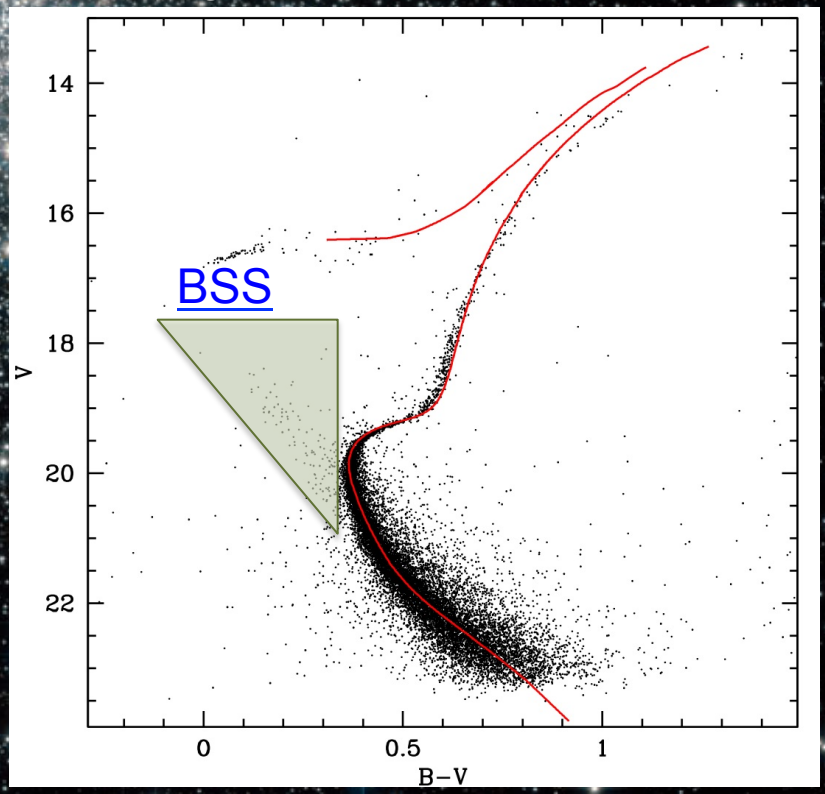
AIM: study of standard stellar evolution models

2) Stellar dynamics

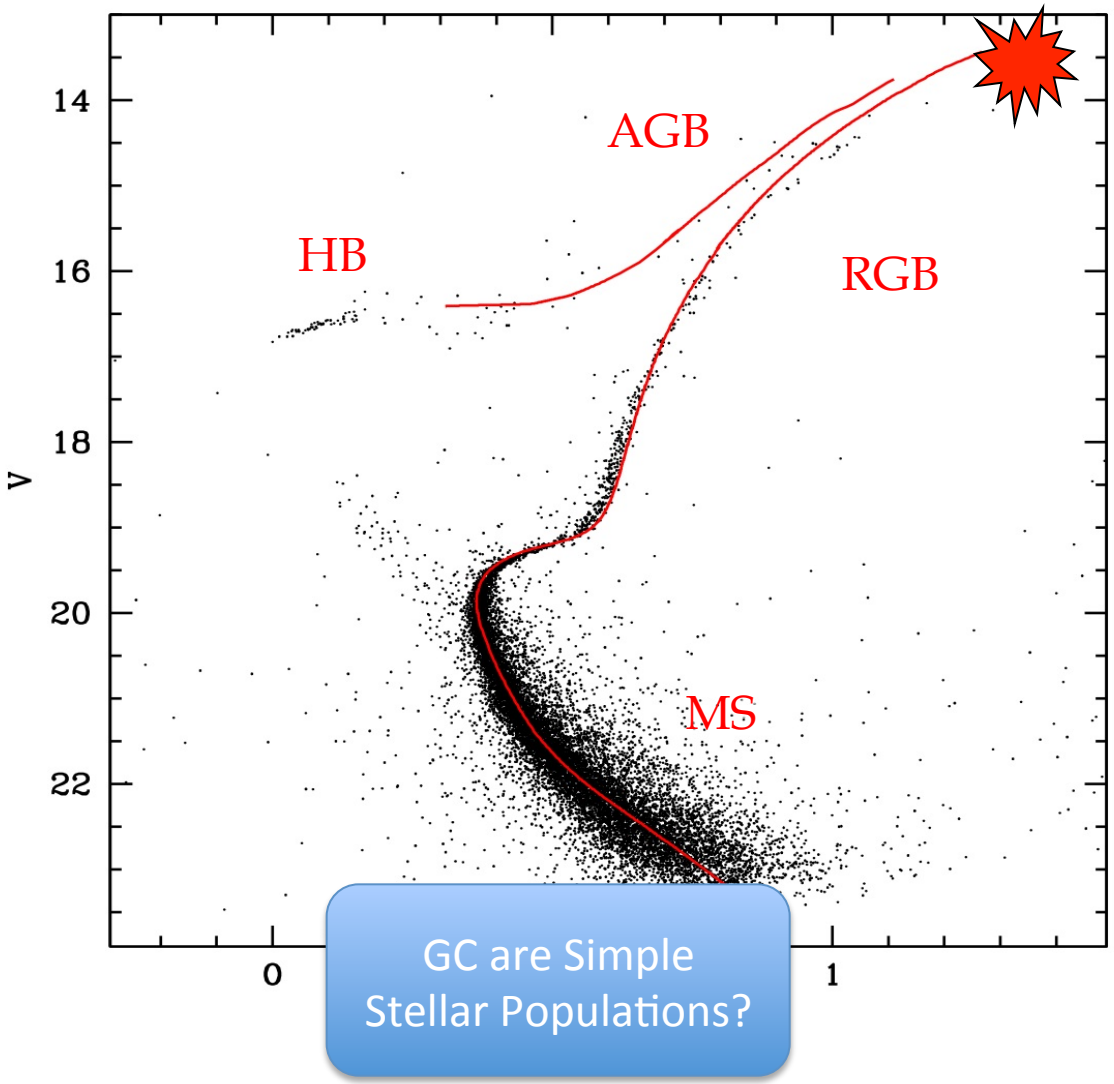
DEF: stars live inside the cluster potential well and interact in double triple or more complex systems (mergers and/or collisions)

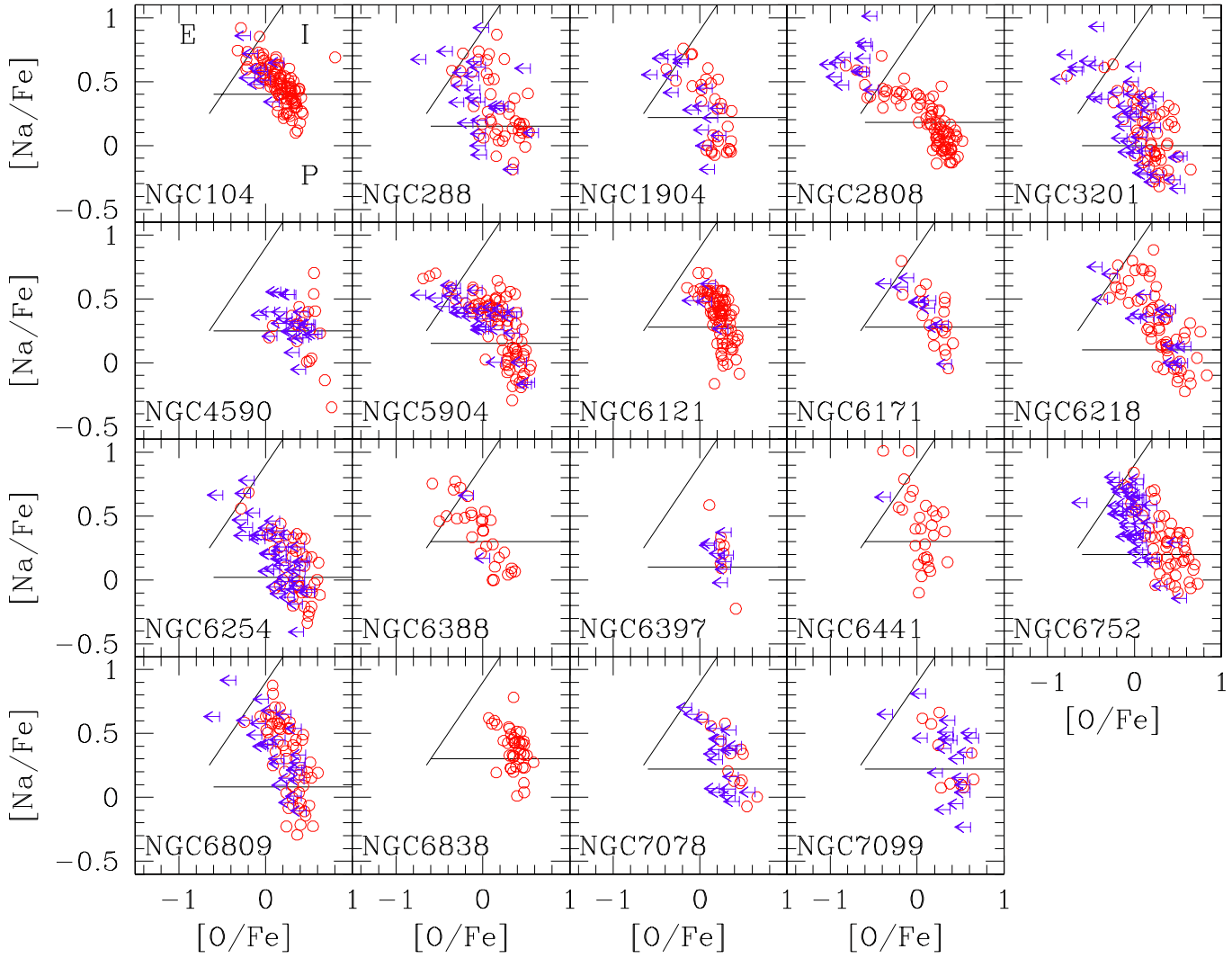
AIM: study of the impact of interactions on the evolution of the star and the hosting cluster



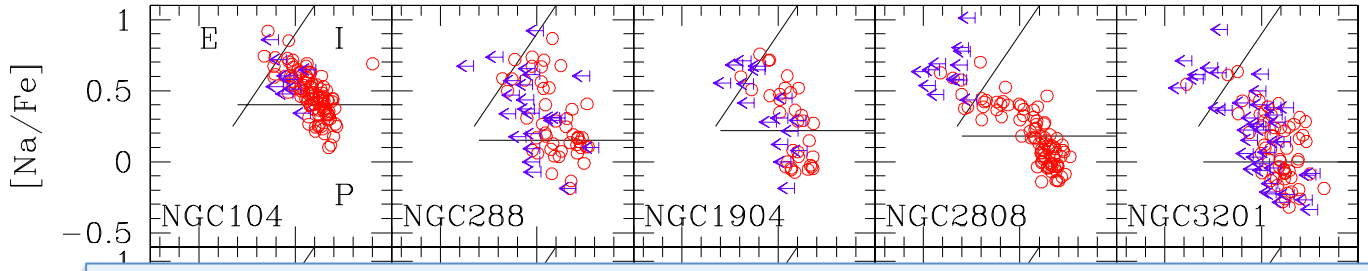


GGCs as a laboratory of Stellar Evolution





~~GC are Simple Stellar Populations?~~



- Eject from massive 1st Gen. enrich the intra cluster medium before formation of 2nd Gen.

(elements cycled through proton capture H-burning reactions at high temperature , CNO, NeNa and MgAl chains) NB. Also N scales as Na

→Massive AGB stars (4Msun<M<6Msun)

→Fast rotating massive starst (FRMS)

→Interactive Binaries+Early Accretion

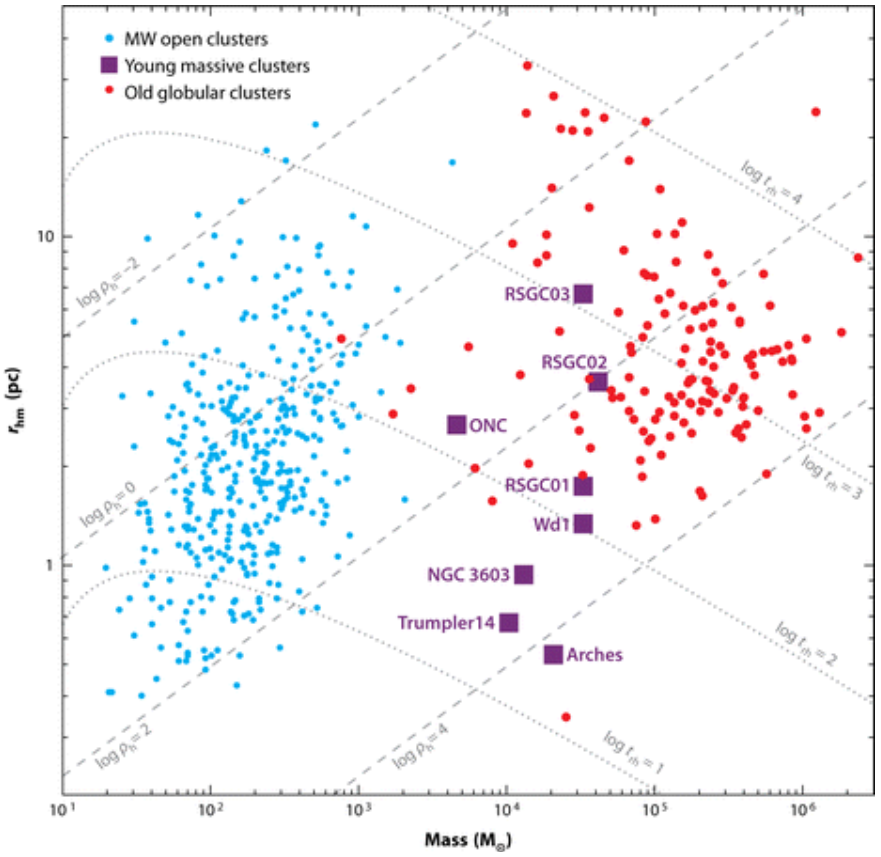
~~GC are Simple Stellar Populations?~~

YMC – Young Massive Cluster

(review S. Portegies Zwart et al. 2010)

cluster	age [Gyr]	m_{to} [$M_\odot$]	M [$M_\odot$]	r_{vir} [pc]	ρ_c [$M_\odot/pc^3$]	Z [$Z_\odot$]	location	t_{dyn} [Myr]	t_{rh} [Myr]
OC	$\lesssim$ 0.3	$\lesssim$ 4	$\lesssim 10^3$	1	$\lesssim 10^3$	~ 1	disk	~ 1	$\lesssim 100$
GC	$\gtrsim$ 10	$\sim$ 0.8	$\gtrsim 10^5$	10	$\gtrsim 10^3$	< 1	halo	$\gtrsim 1$	$\gtrsim 1000$
YMC	$\lesssim$ 0.1	$\gtrsim$ 5	$\gtrsim 10^4$	1	$\gtrsim 10^3$	$\gtrsim 1$	galaxy	$\lesssim 1$	$\lesssim 100$

stellar masses: 10^4-10^5 $M_\odot$



(review S. Portegies Zwart et al. 2010)

"…multiple populations should be expected in at least some young star clusters, but it is currently not known whether, or to what extent, this phenomenon occurs in observed YMCs."

The study of SF in massive young clusters can help us to understand how temporally and spacially extended star formation could occurs within star clusters

GGCs as a laboratory of Stellar Dynamics

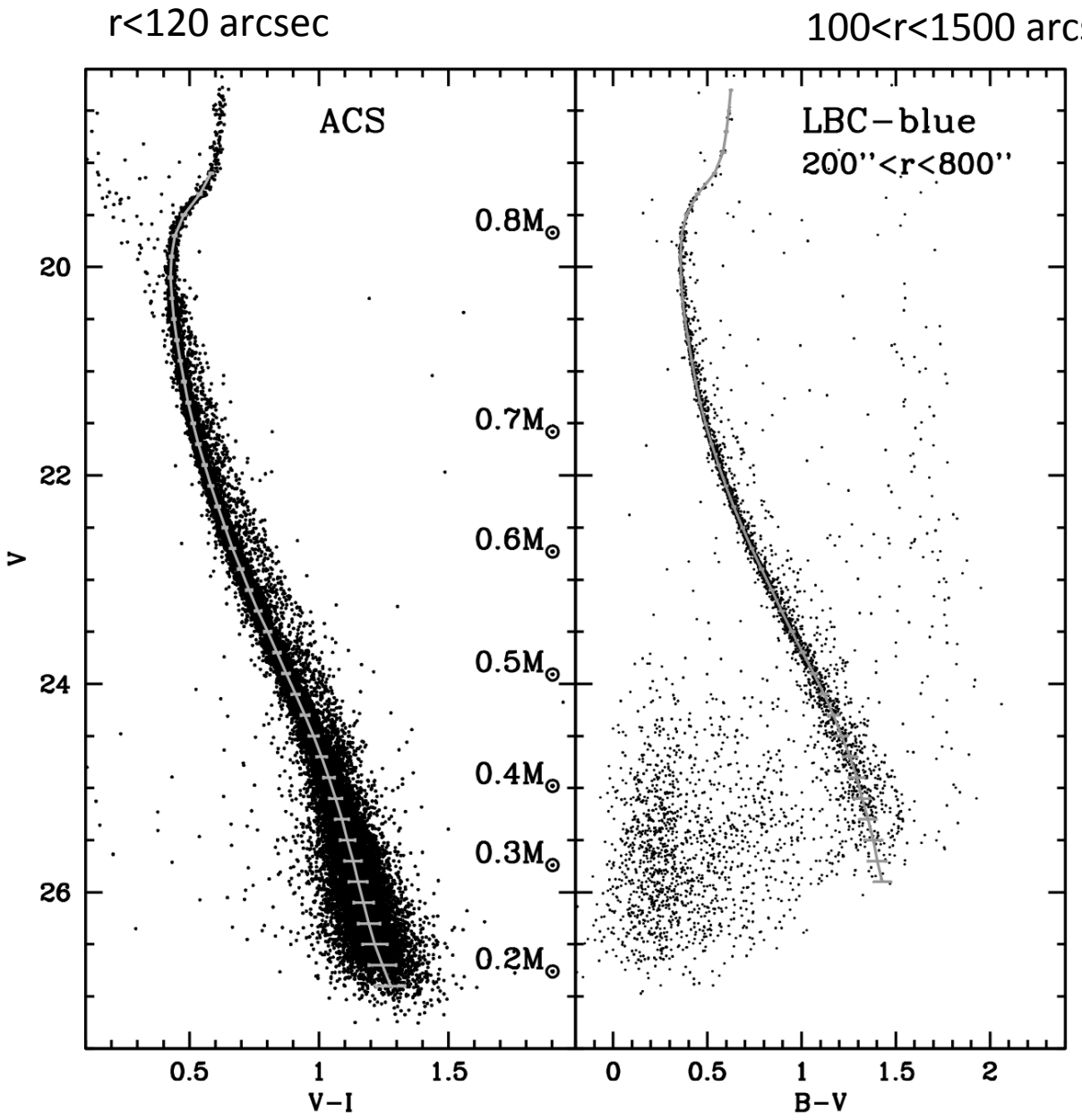
To Constrain Globular Cluster dynamics using mass segregation

WHAT - Mass segregations is a collisional effect: Massive stars (and remnants) move to the core, least massive stars move out

WHY - Mass segregations is a strong observational feature (compare to e.g. evaporation of stars, core collapse etc.)

High res. Imaging (HST) + Wide Field on 8-10m telescopes (LBC@LBT) sample 0.8-0.2 Msun

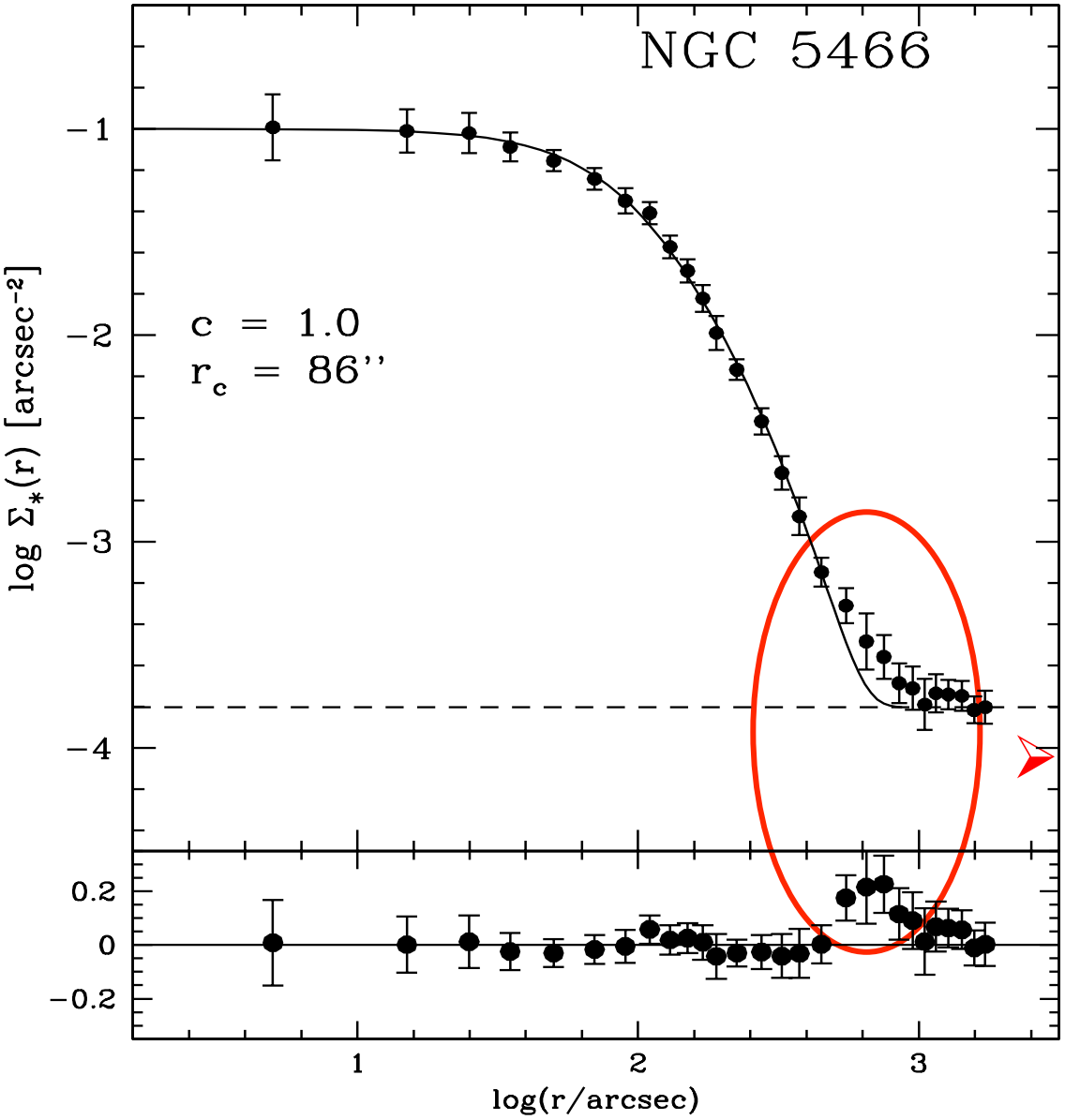
NGC 5466-the radial distribution of the MF



Beccari et al. 2013, ApJ, 776, 60; Beccari et al., in prep.

GCs: radial density profile

- Fit with standard King Model allows an estimate of cluster dynamical parameters



➢ **Tidally stripped stars**

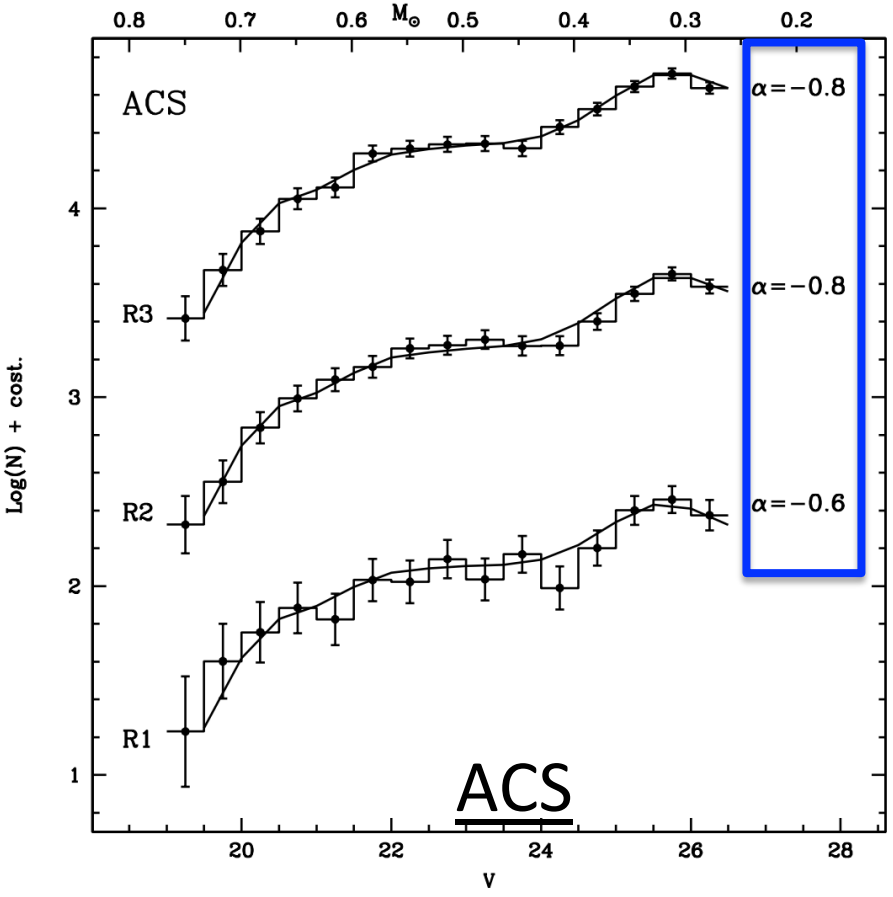
NGC 5466
The LF and MF

Luminosity Function (LF)
vs
TLF obtained by multipl. a simple power-law MF by the derivative of the M-L from Dartmouth mod.

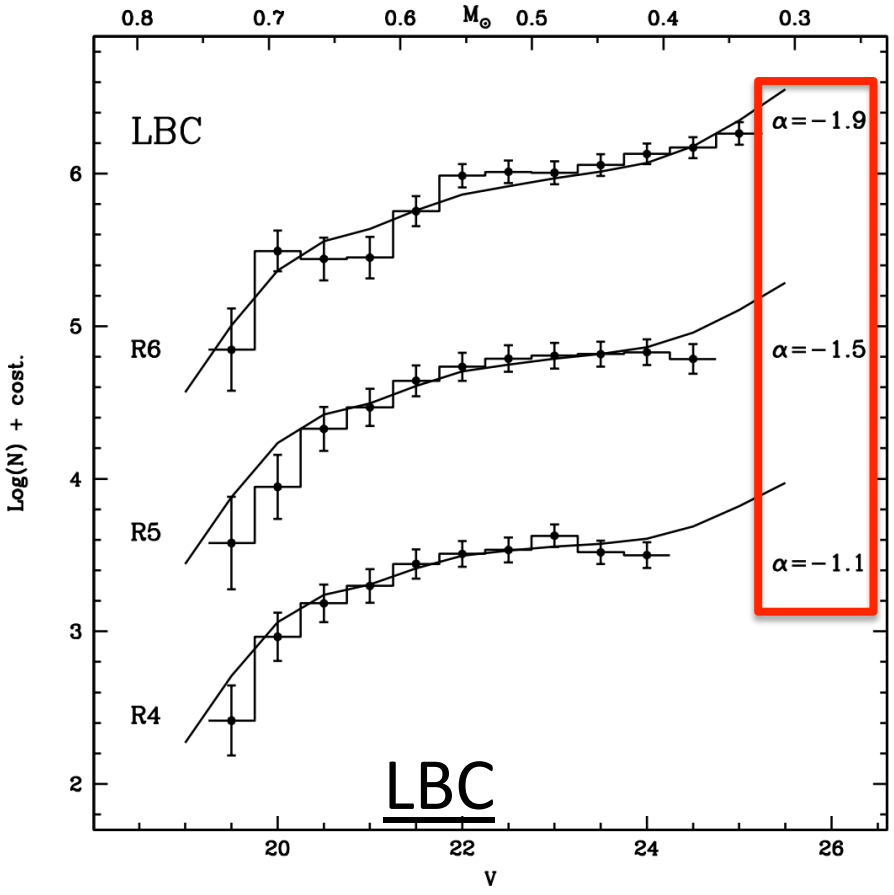
$$dN/dm \propto m^{\alpha}$$

- Salpeter α=-2.35
- α>0 – N decreasing with mass

NO MASS SEGREGATION IN r<100''



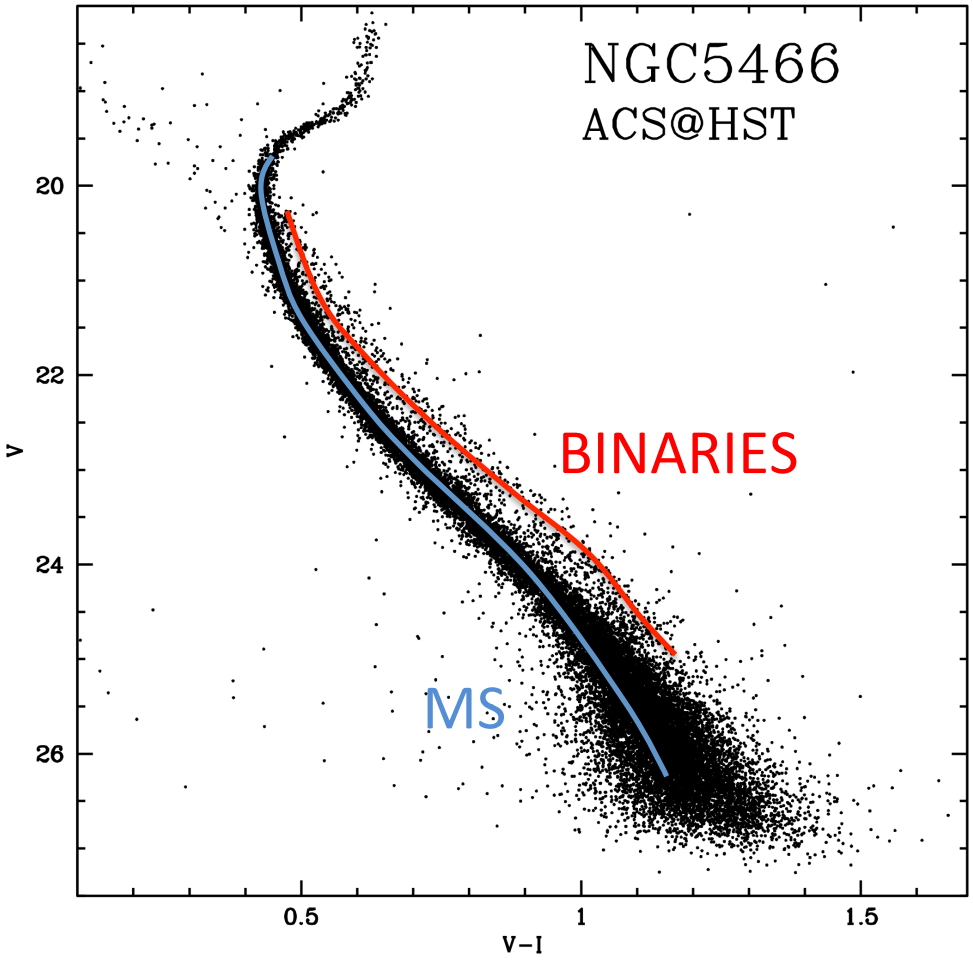
MASS SEGREGATION OUTSIDE

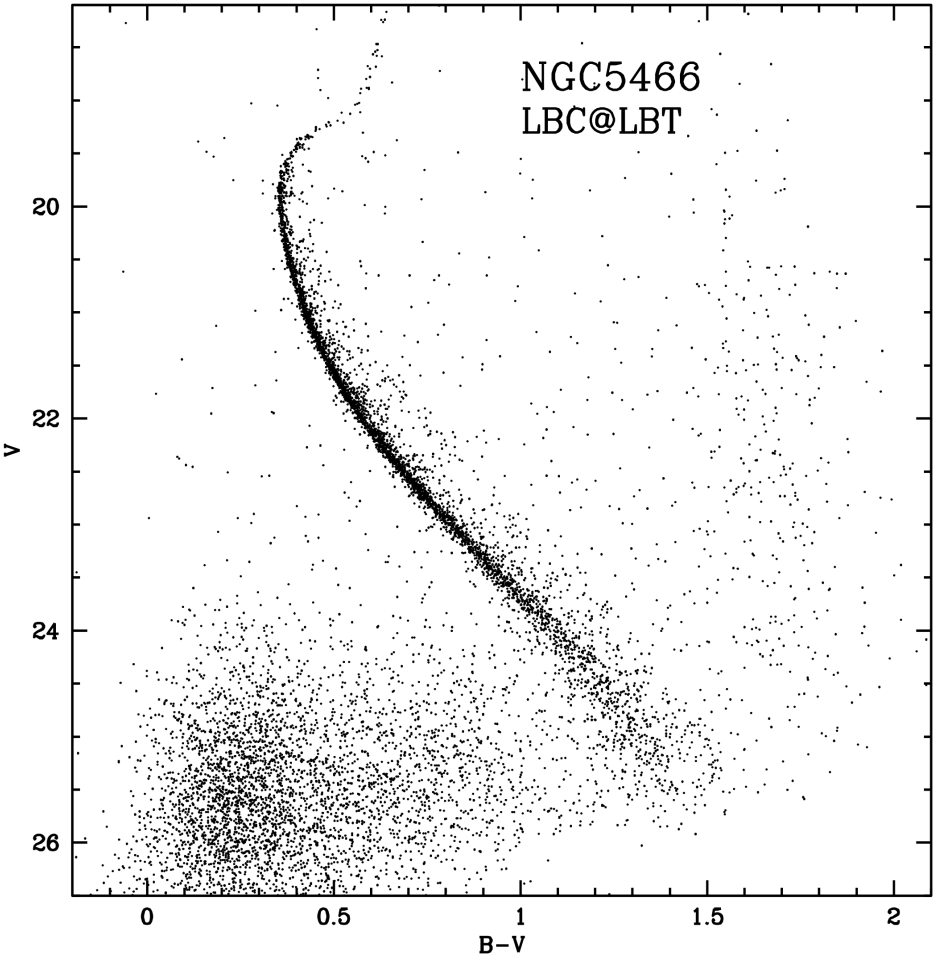


Beccari et al. 2013, ApJ, 776, 60; Beccari et al., in prep.

NGC 5466-the radial distribution of binary frac.

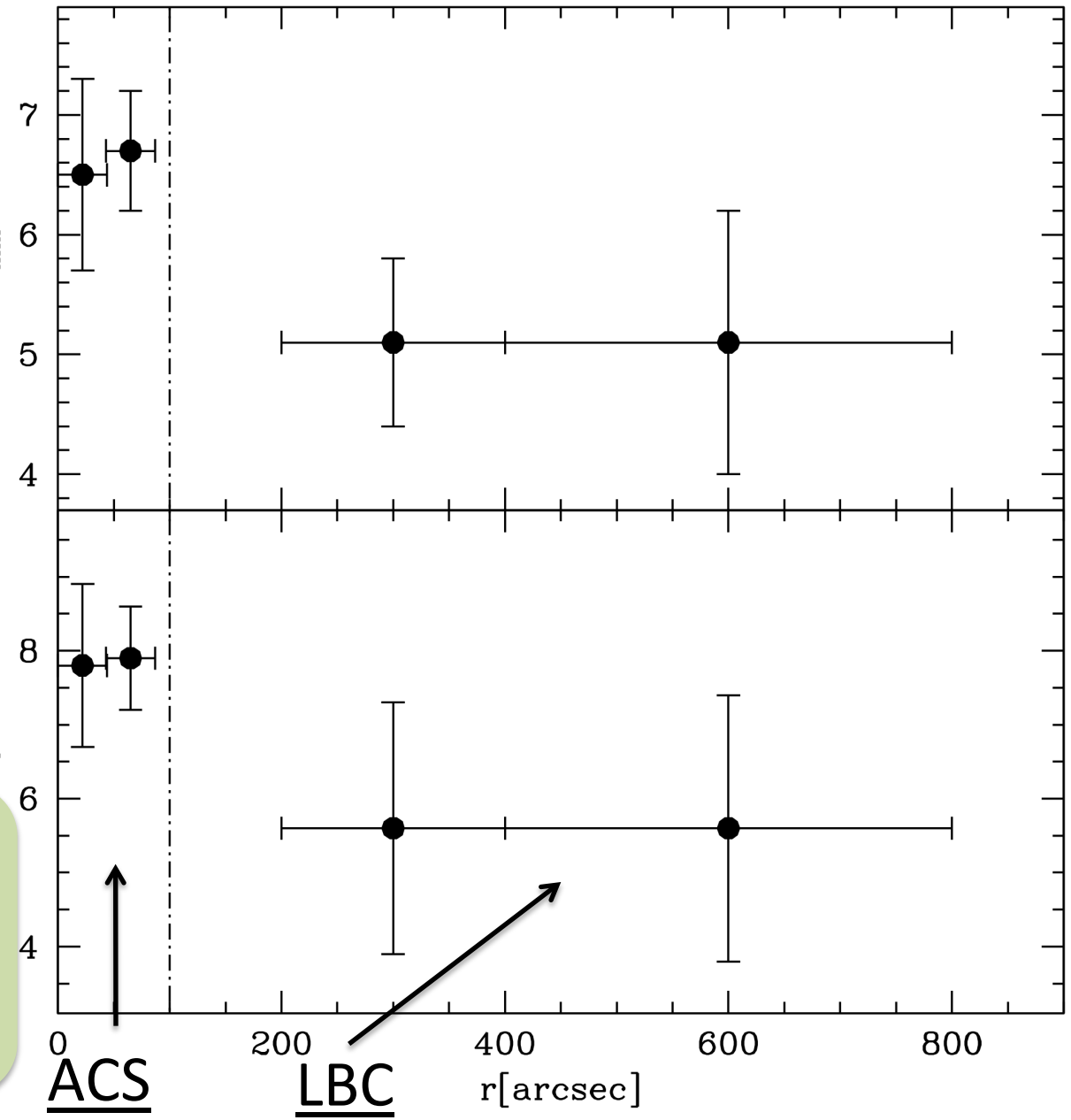
Binaries “populate” a S-MS depending on q=M1/M2





NGC 5466-the radial distribution of binary frac.

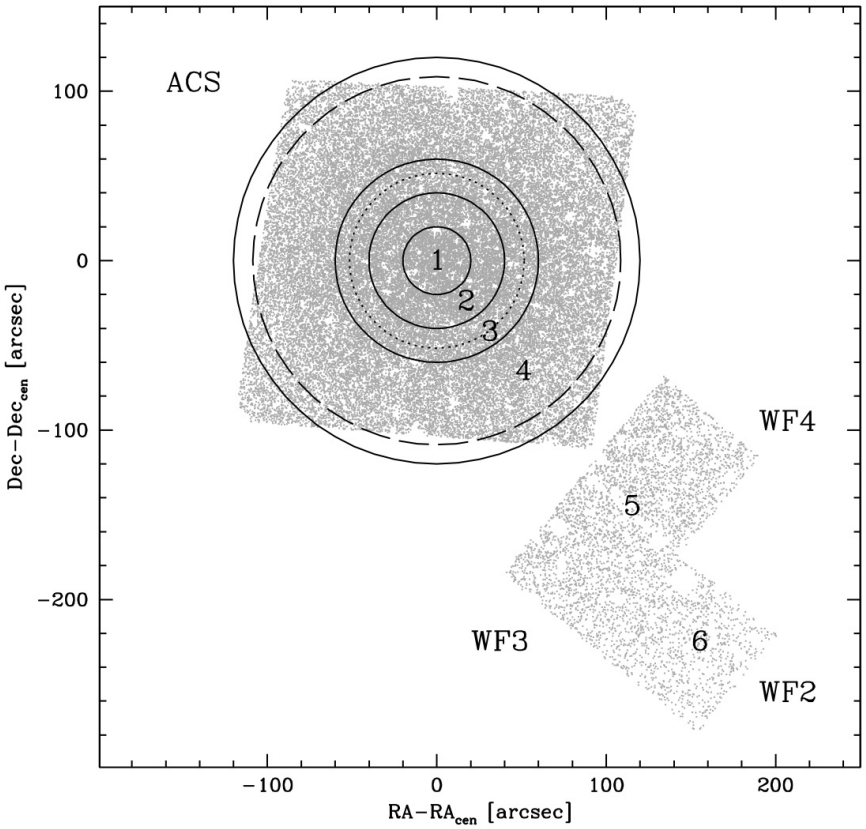
Bin_F	Bin_min	r[arcsec]
7.8	6.5	22
7.9	6.7	65
5.6	5.1	300
5.6	5.1	600

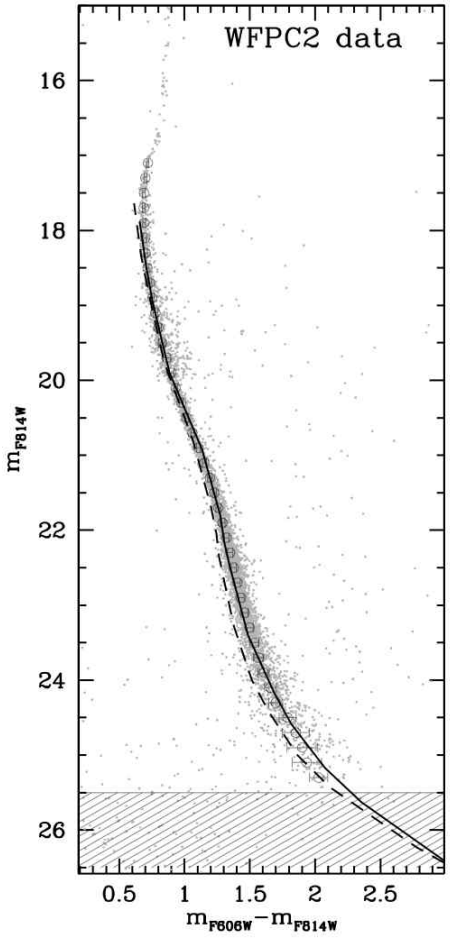


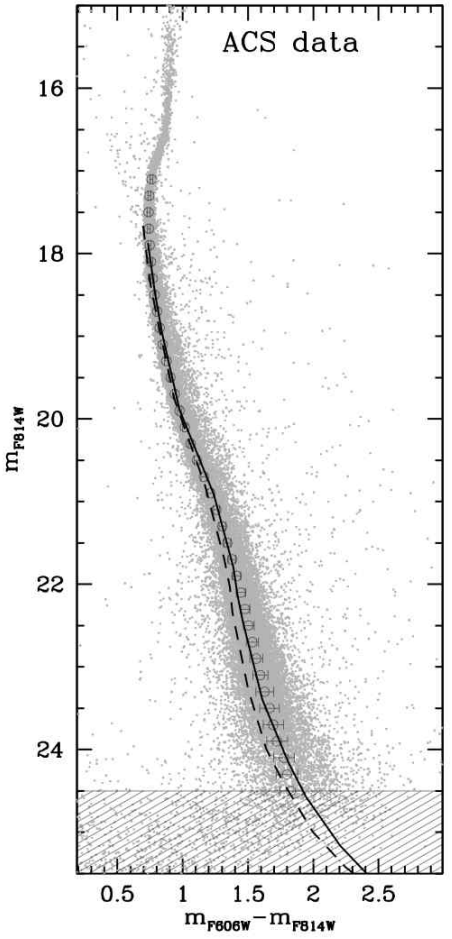
✓Binaries are centrally segregated!
✓They share the same mass segregation assessed with the study of the LF and MF

Mass Segregation in M10: binary stars or IMBH?

M10
rc=0.84′
rh=2′
log(th)=8.7
Age~12Gyr

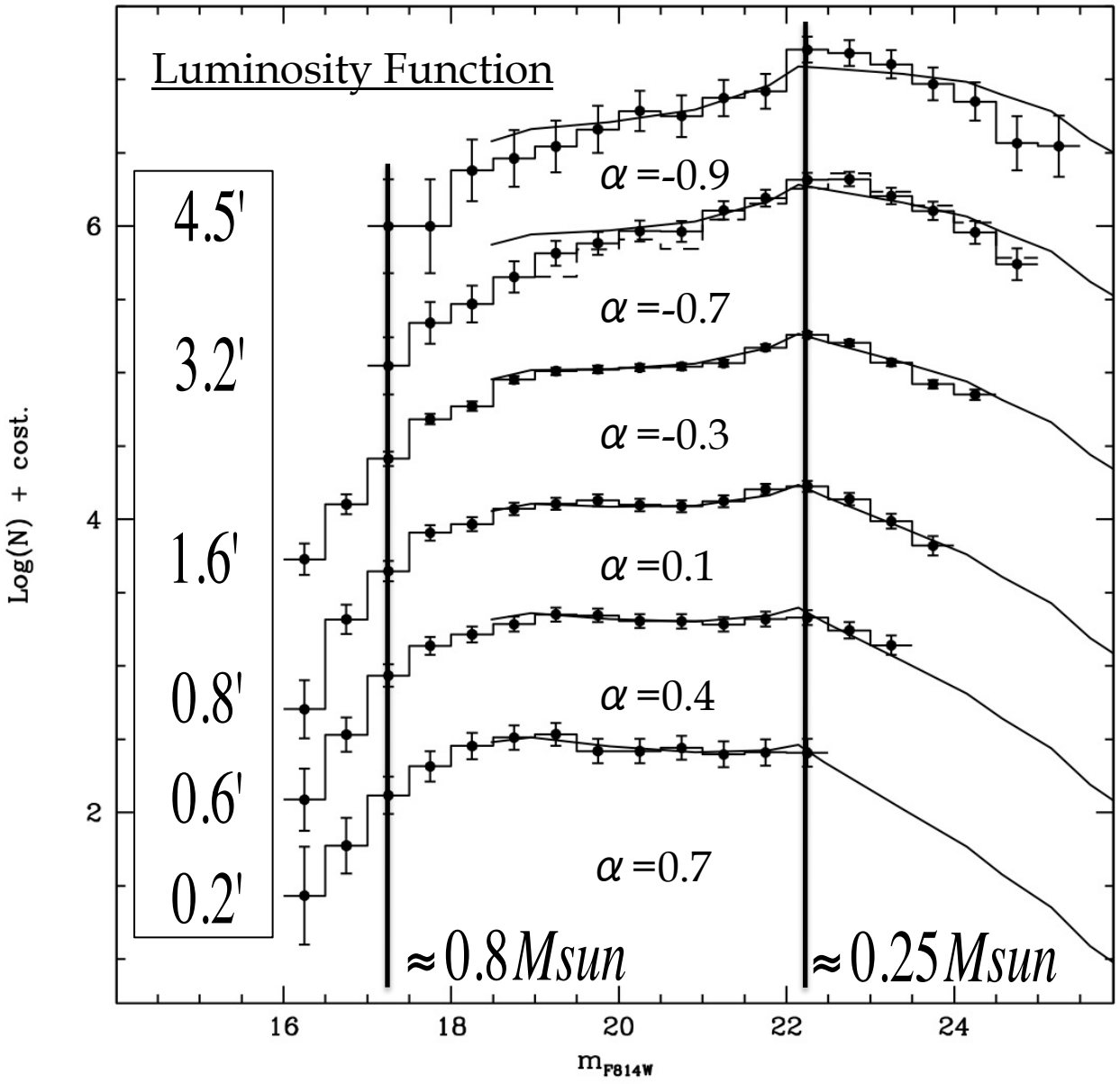






Beccari et al. 2010, ApJ, 713, 194

Mass Segregation in M10: binary stars or IMBH?



M10
rc=0.84′
rh=2′
log(th)=8.7
Age~12Gyr

Luminosity Function (LF)

⇩

Mass Function (MF)
M-L from Baraffe et al 1997

$$dM/dm \propto m^{\alpha}$$

- Salpeter α =-2.35
- α >0 – N decreasing with mass

M10 is segregated

- Muti-mass Michi-King model

M10 is a condition of equipartition of energy

Beccari et al. 2010, ApJ, 713, 194

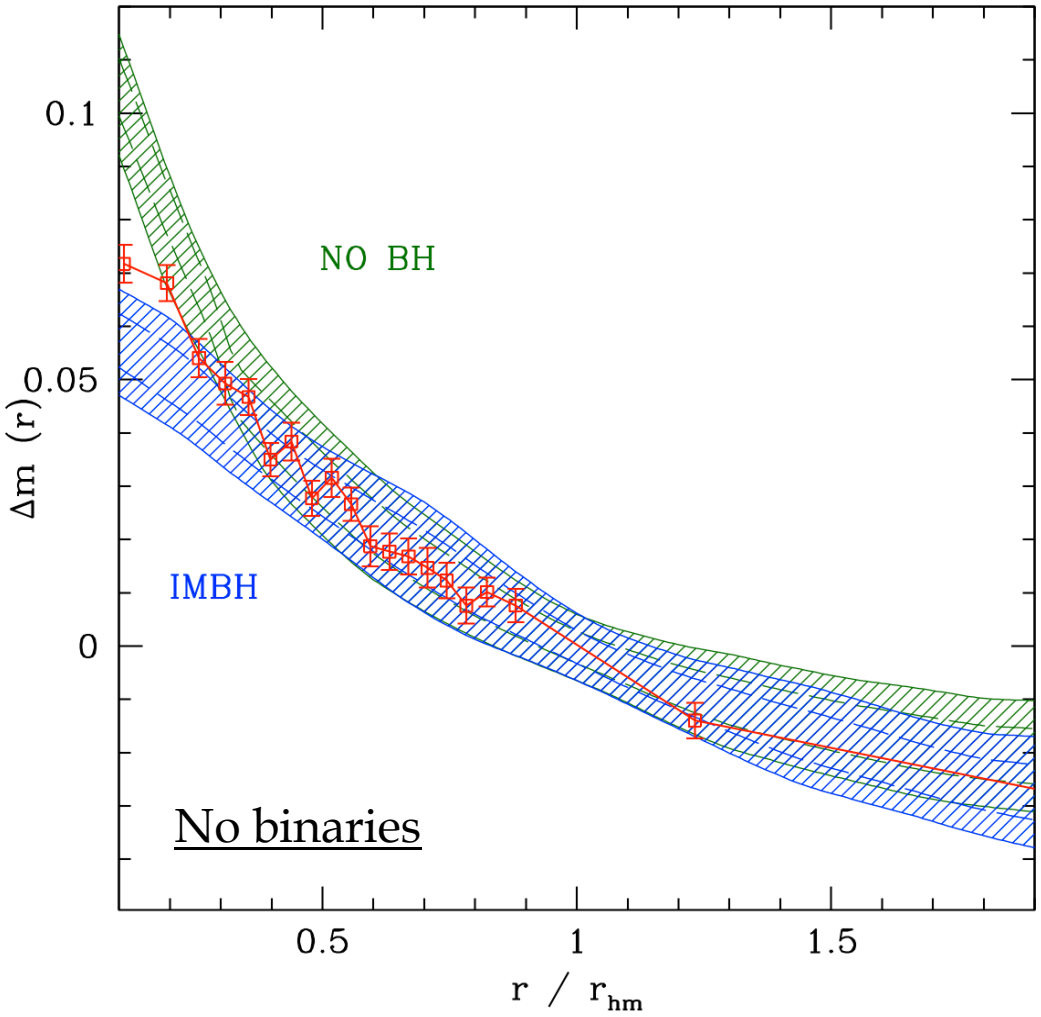
Observations

Observed radial mass segregation profile ($\Delta m(r)=\langle m\rangle_{MS}(r)$ in M_{sun})

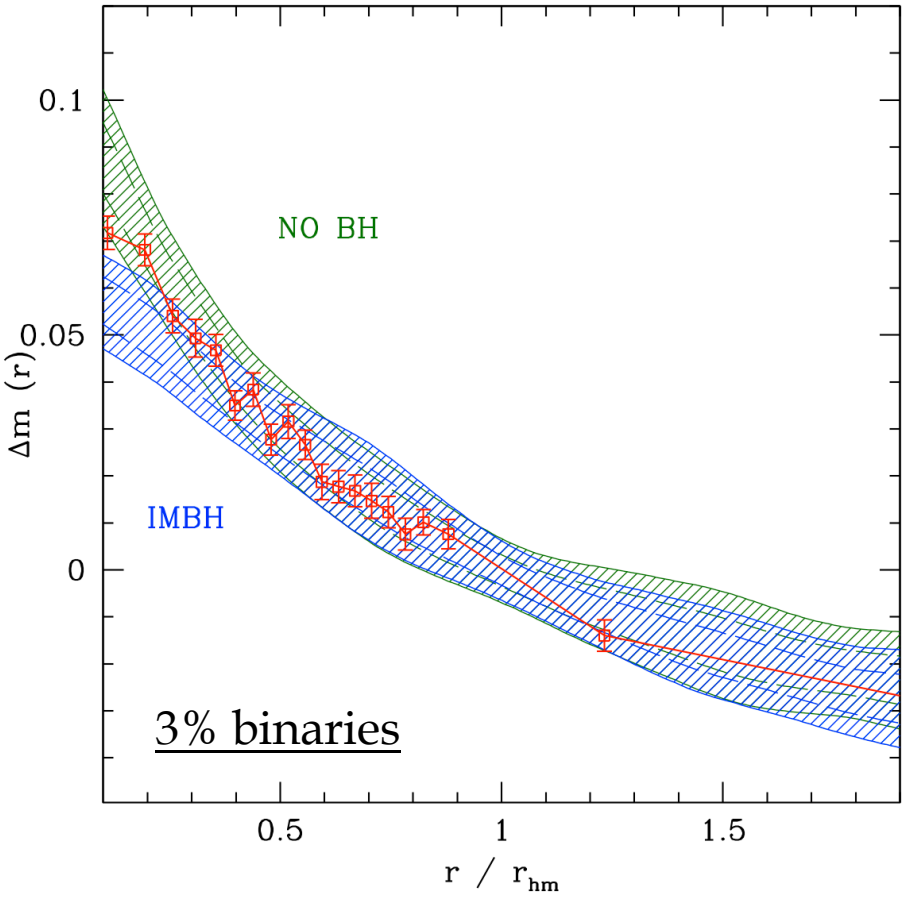
N-BODY simulations

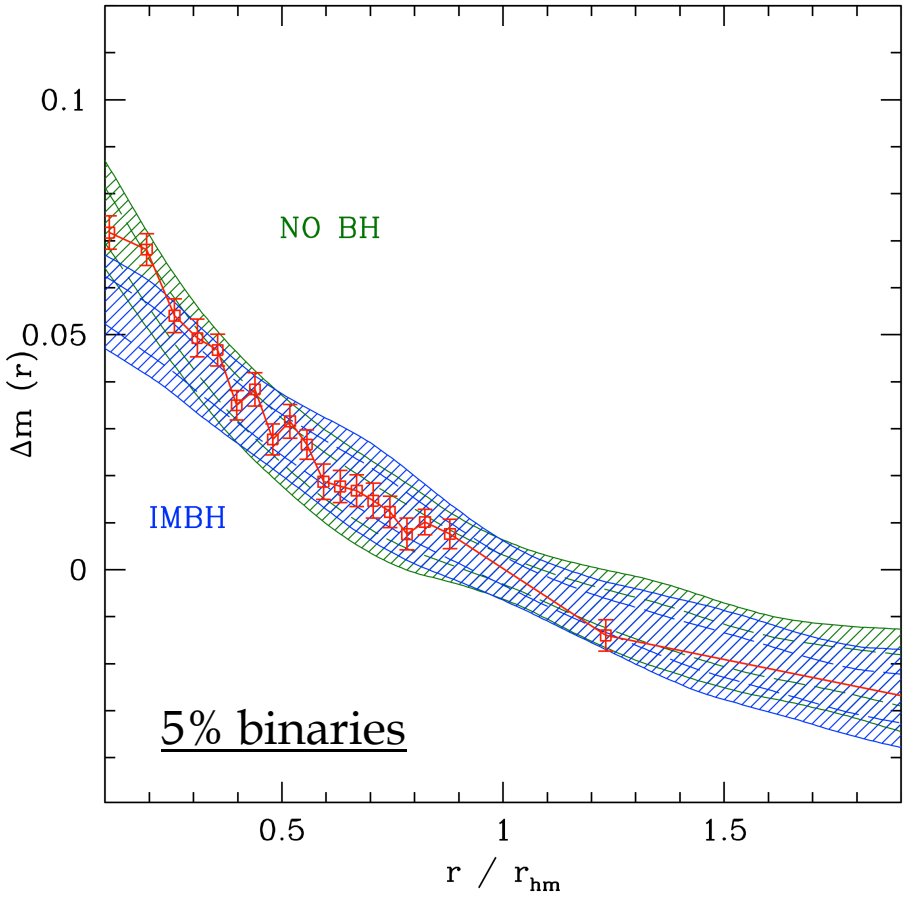
With IMBH of ~1% of GC mass

Without IMBH of GC mass



A *source of energy* is actively quenching mass segregation in the cluster:
Binaries (3-5%)





Measure of Mass segr. + Dynamical measurement of the binary fraction

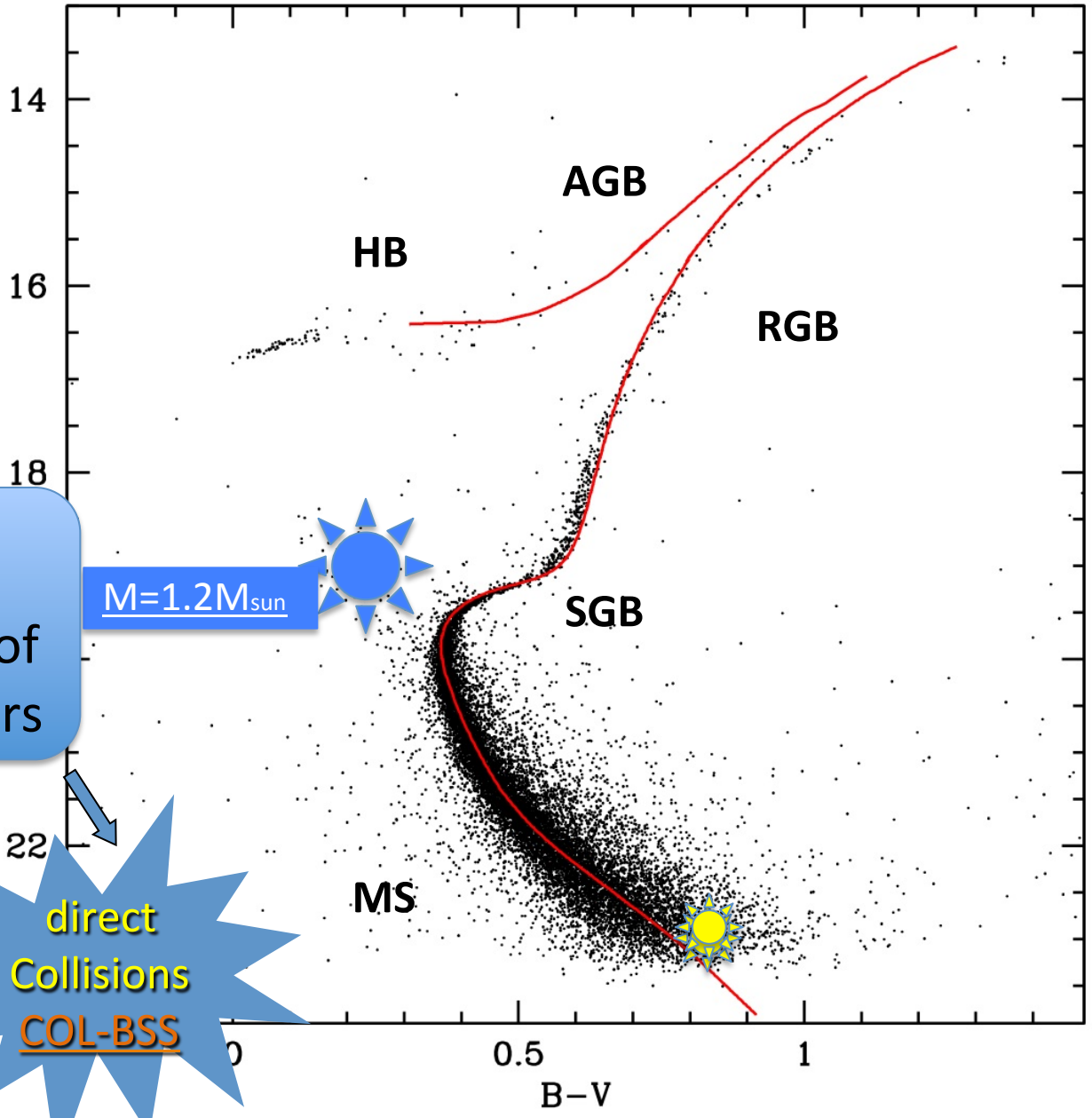
Studying the MF is an efficient way to study the mass segregation and the clusters' dynamical evolution…..BUT…..

….needs deep and high quality data!!!

Measure of Mass segr. + Dynamical measurement of the binary fraction

The BSS: a new way?

Canonical Evolutionary Sequences



BSS
Merger of
2 MS stars

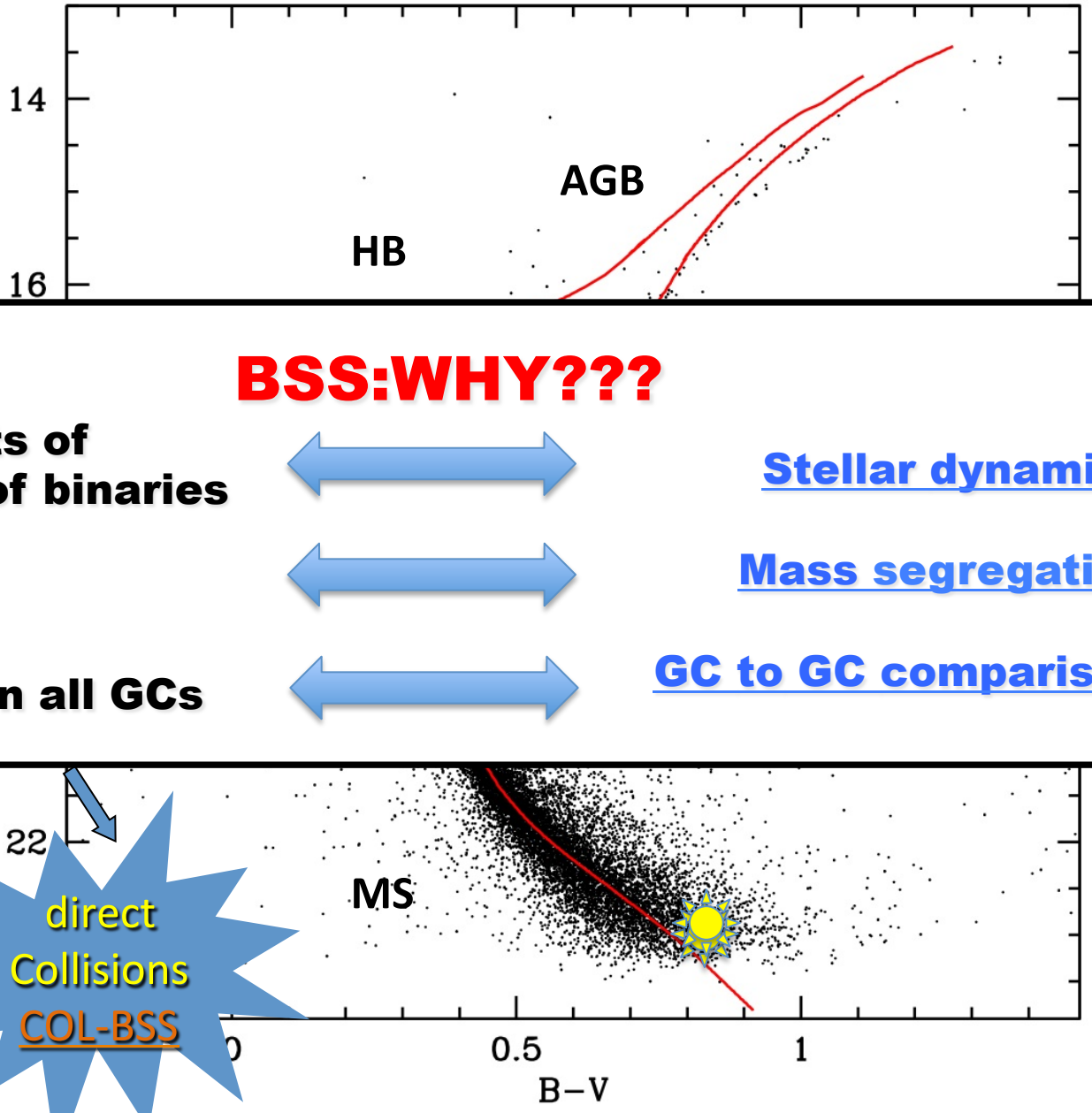
M=1.2M$_{sun}$

primordial
Binaries
MT-BSS

direct
Collisions
COL-BSS

The BSS: a new way?

Canonical Evolutionary Sequences



BSS:WHY???

>by-products of evolution of binaries ⟷ Stellar dynamics

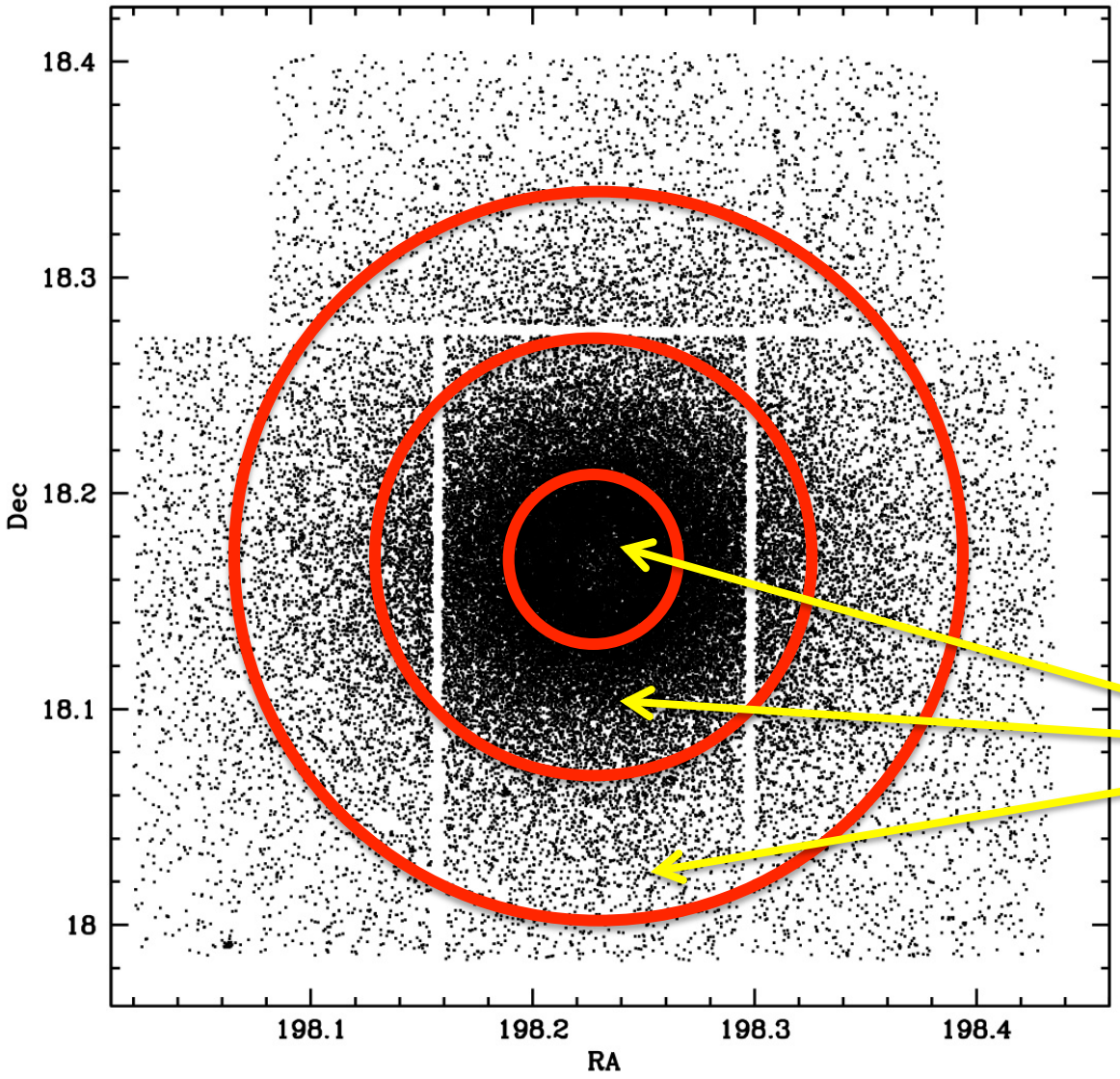
>massive ⟷ Mass segregation

>observed in all GCs ⟷ GC to GC comparison

primordial Binaries MT-BSS

direct Collisions COL-BSS

The BSS radial distribution



For a sample of ~ 14 GCs

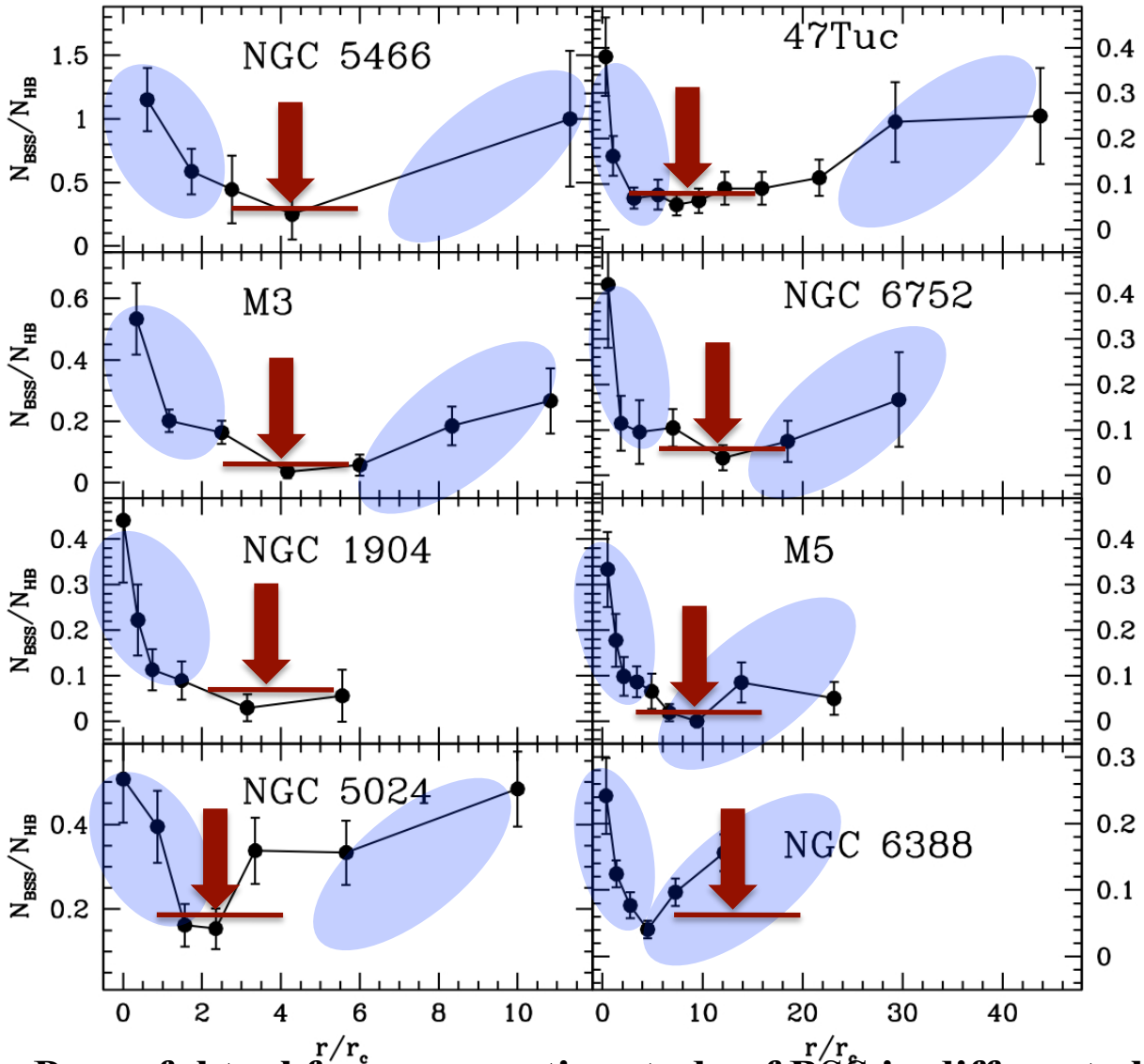
1-Population Selections

2-Division of the FoV in concentric anuli

3- Ration of N(BSS)/N(POP)

$$\frac{N(BSS)}{N(POP)}$$

BSS and Mass Segregation



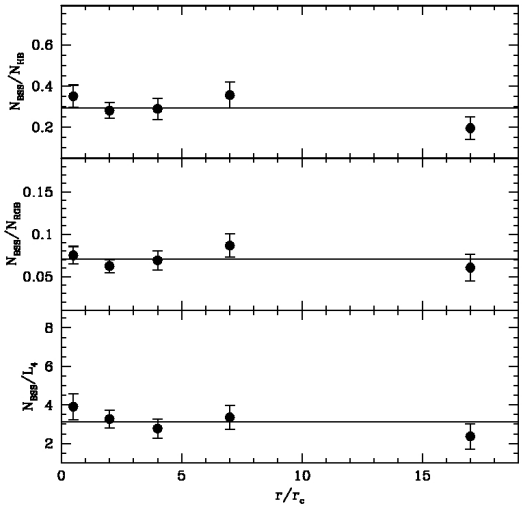
In most cases BSS show a BIMODAL radial distribution

Radius at which all objects with a mass similar to BSS (~1.2Msun) have been sunk into the core (because of dynamical friction) in a time comparable to the cluster age

Powerful tool for comparative study of BSS in different globular cluster

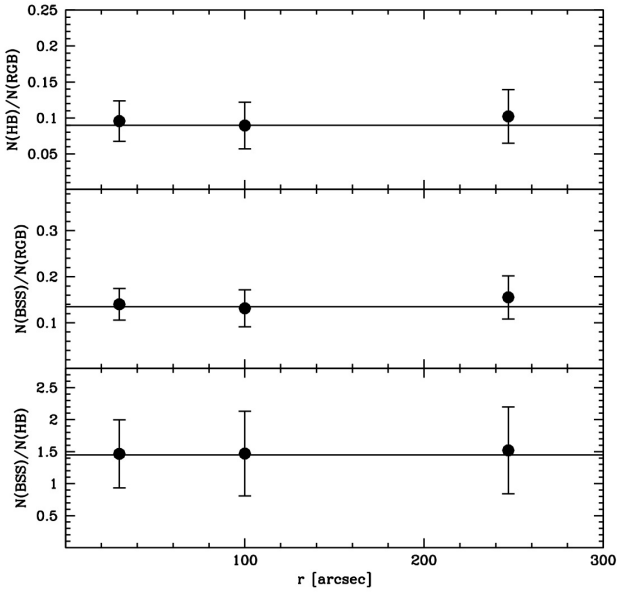
(Bailyn et al. 1995; Ferraro et al. 2003, 2004,2006,2012; Beccari et al. 2006, 2008, 2009, 2011, 2012, 2013; Lanzoni et al. 2007a,b,c,d; Dalessandro et al. 2008a,b;2010)

NGC 2419



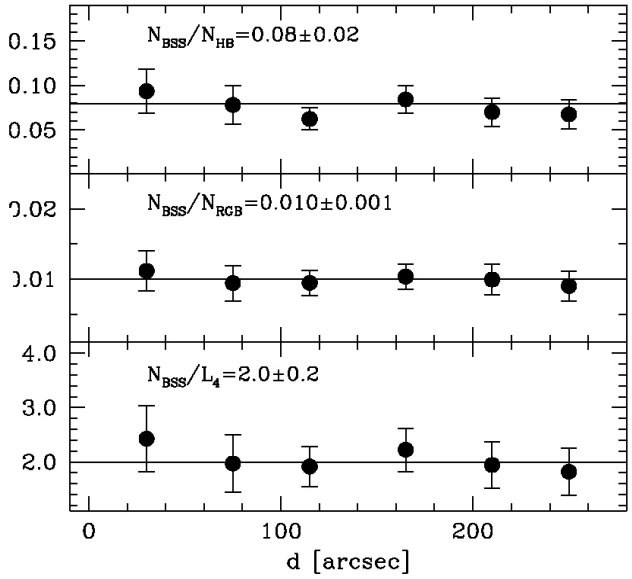
Dalessandro et al. (2008)

Palomar 14



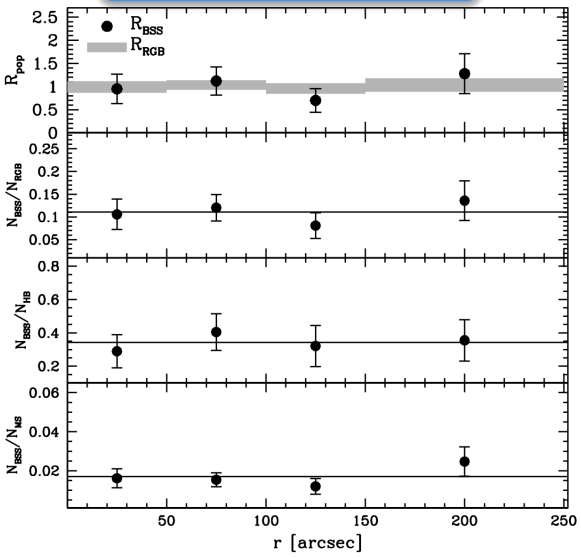
Beccari et al. (2012)

ωCen



Ferraro et al. (2006)

NGC 6101

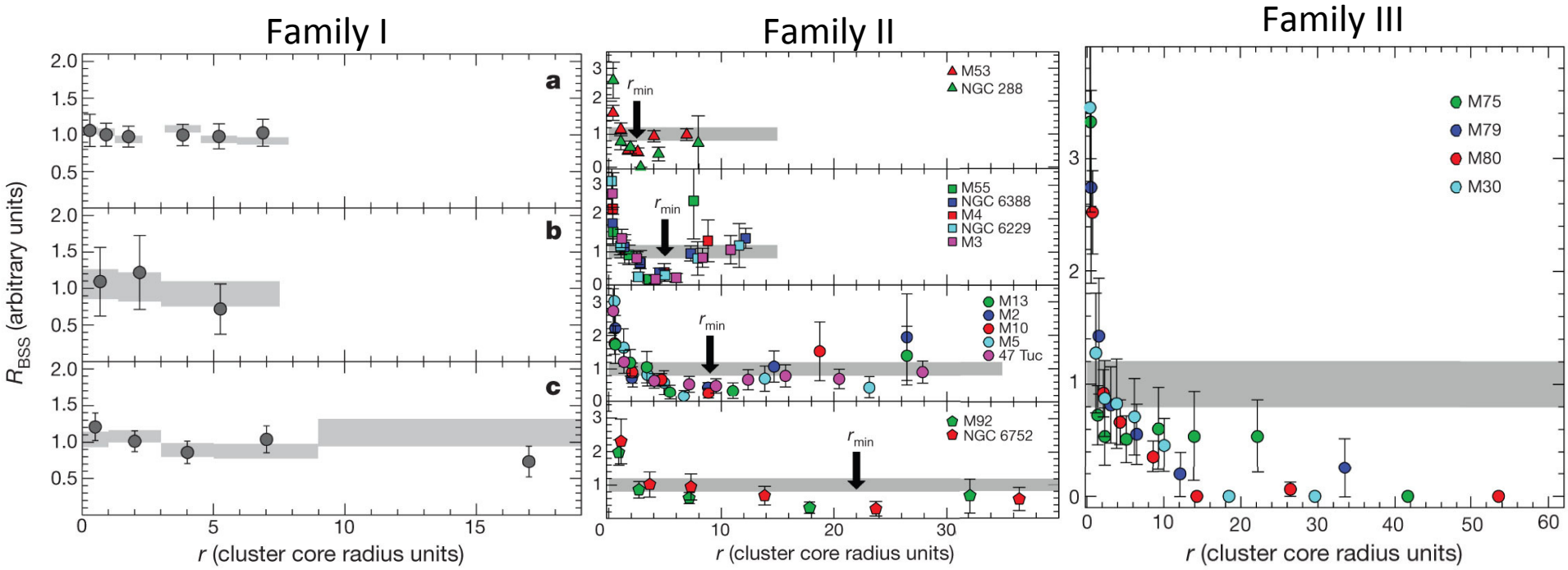


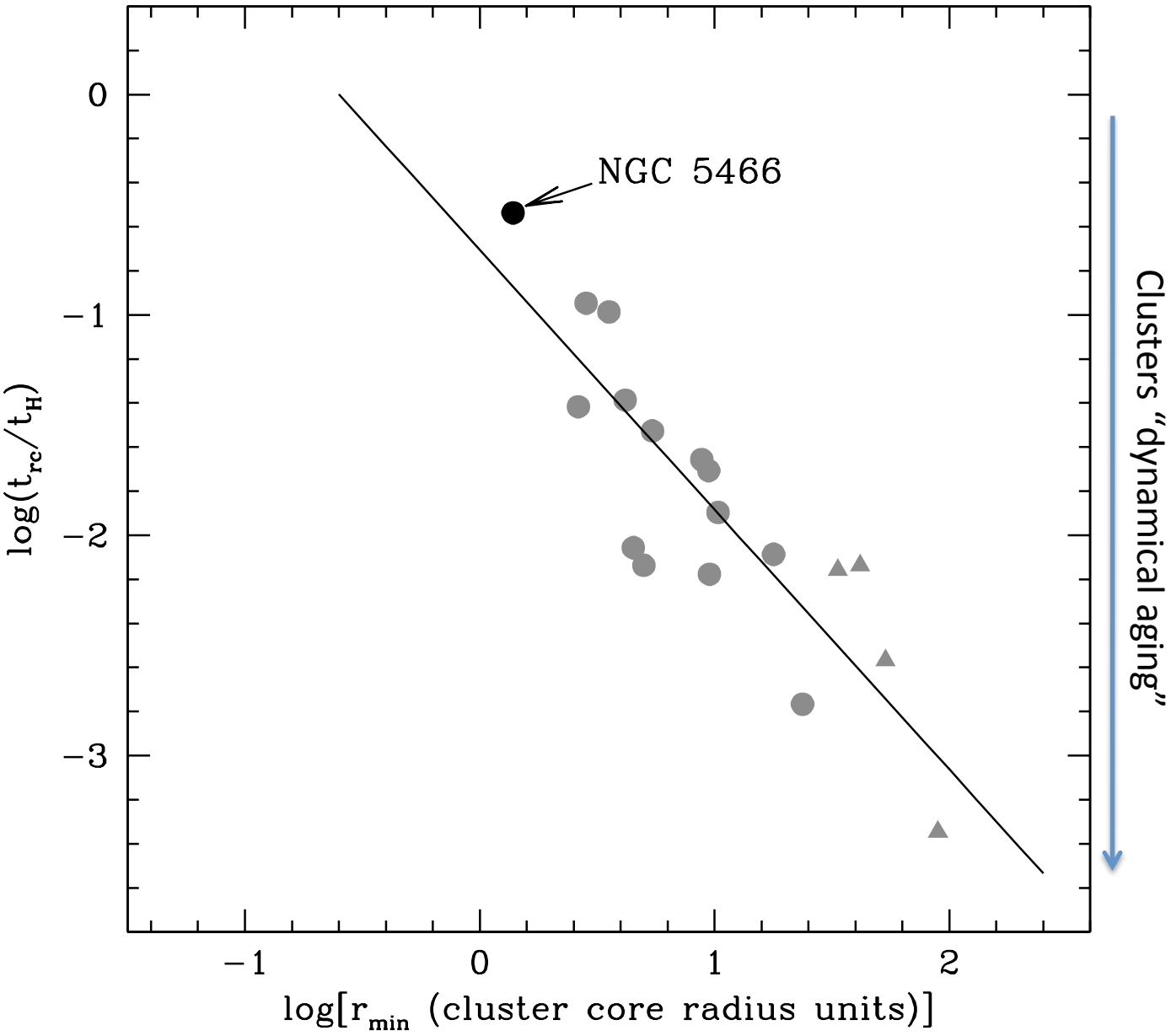
Dalessandro et al. (2015)

NO SIGNATURE OF MASS SEGREGATION

BSSs: a dynamical clock

Ferraro et al. 2012, NATURE: BSS as particle test to probe the dynamical state of GCs;
Dynamical Clock



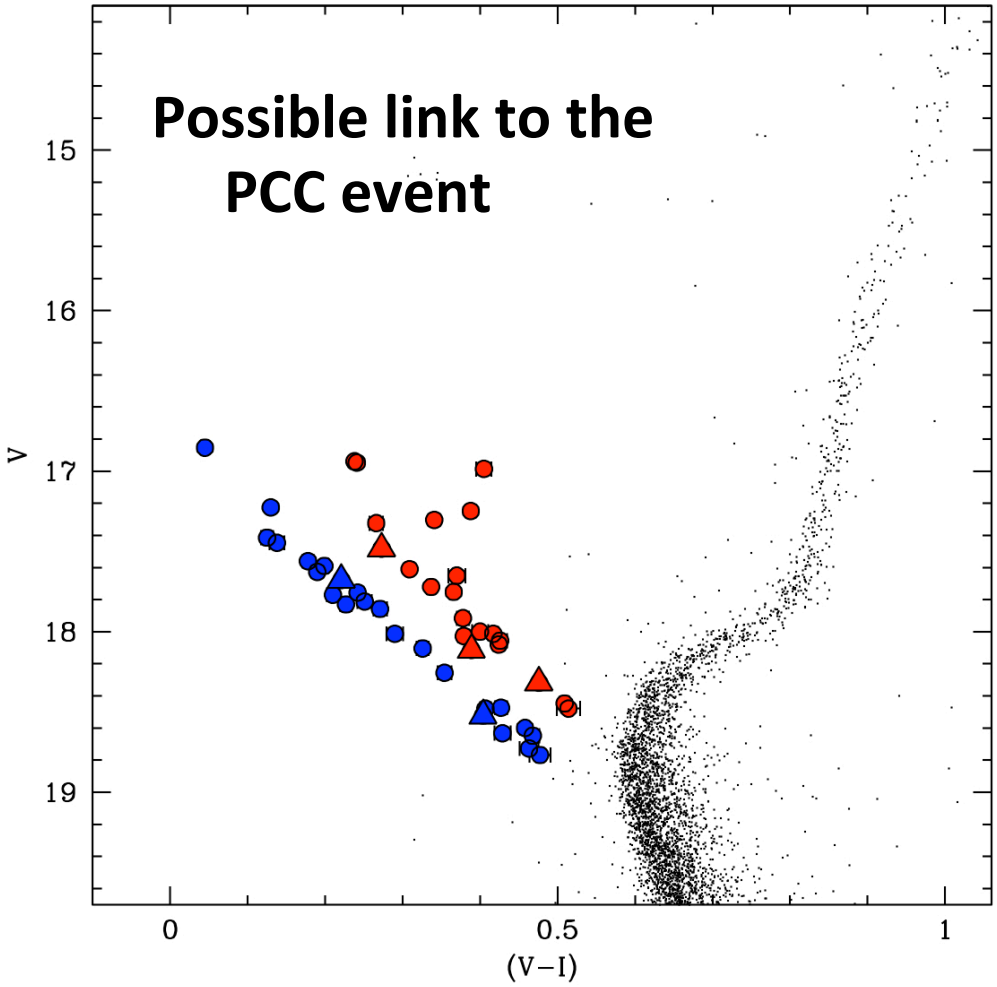

NGC 5466
Clusters "dynamical aging"
log(t_rc/t_H)
log[r_min (cluster core radius units)]
0
−1
−2
−3
−1
0
1
2

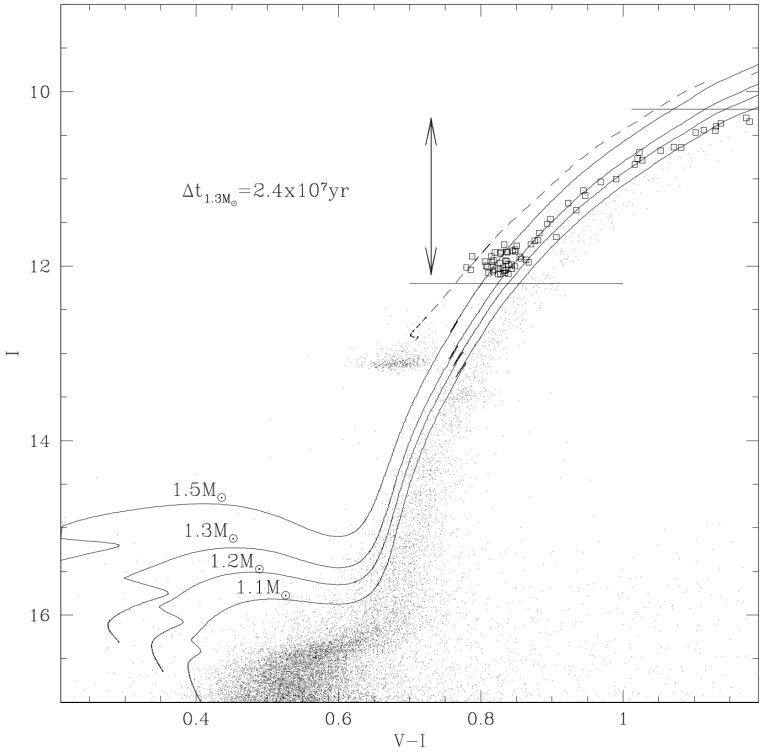
…. Indeed we can do even more….

2 distinct sequences of BSS !!

Ferraro, Beccari et al. (2009, Nature 462, 1028)

Contamination by non genuine low-mass AGB ???





Summary and Conclusions

BSS

Binary stars

Study of LF/MF

Dynamics in GCs

- More data (HST; FORS2; FLAMES; XSHOOTER)
- N-BODY simulations