Properties of blue straggler populations in evolving star clusters based on the MOCCA dynamical simulations

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Thank you

- Thank you for having me here!
- Thank you for the financial support!

Outline

- Influence of initial conditions on blue straggler populations
- Spatial distribution of blue stragglers (bimodal, unimodal, flat)

Why GCs? Why BSs? Why MOCCA?

Toolkit

Why GCs?

- efficient environment to create exotic objects (e.g. BSs)

Why BSs?

- they might reveal complex interplay between stellar evolution and stellar dynamics
- two channels of formation: collisions and mass transfer

Why MOCCA?

- it is a Monte Carlo method, but still:
  - it provides as many details as N-body codes
  - it follows the N-body codes very closely (Giersz 2013)
- it is fast $\Leftrightarrow$ one can compute many models

Influence of the initial conditions on the population of BSs

Can BSs help to narrow down the initial binary properties?

The initial MOCCA models

- many models with different:
  - N (300k, 600k)
  - f_b (0.1 - 0.5)
  - mass ratios (uniform, random)
  - semi-major axes
    - uniform in log scale up to 100 AU
    - lognormal distribution up to 100 AU
    - binary period distribution Kroupa (1995)
    - eigenevolution and feeding algorithm Kroupa (1995)
    - new eigenevolution and feeding algorithm Kroupa (2013)
  - eccentricities (thermal, thermal + eigenevolution)
  - r_{tid} (15 - 400 [pc])
  - r_h (1 - 40 [pc])
- essentially 2 groups to test:
  - influence of the initial conditions on the population of BSs
  - formation of the bimodal distribution

BASE model - radii

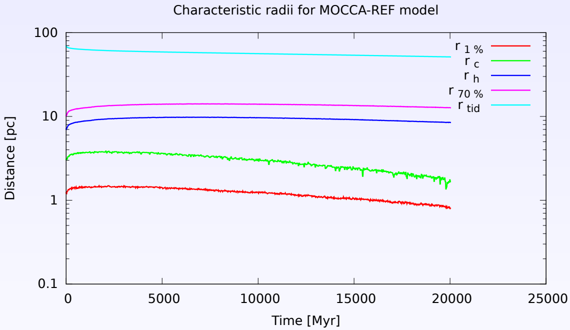


Figure: Specific radii for the BASE model

- 300k, $f_b = 0.2$
  - f_b slightly higher than in MW GCs to have more BSs
- Plummer model, IMF = Kroupa (1991, 1993)
- q = U, a = UL, e = T, z = 0.001
- r_{tid} = 69 [pc]
- $c = r_{tid}/r_h = 10$, r_h = 6.9 [pc]
- slow increase of the density, no core-collapse
- quite standard model, nothing unusual

BASE model - population of BSs

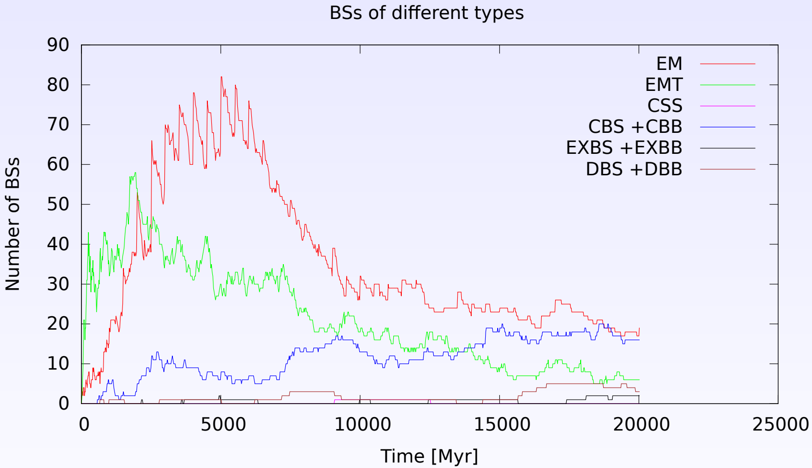


Figure: Population of BSs of different types for the BASE model: EM (Evolutionary Merger), EMT (Evolutionary Mass Transfer), CBS+CBB (Collisional Binary-Single/Binary-Binary), EXBS+EXBB (Exchange . . .), DBS+DBB (Dissolution . . .)

Different semi-major axes distributions

BASE model vs. lognormal semi-major axes

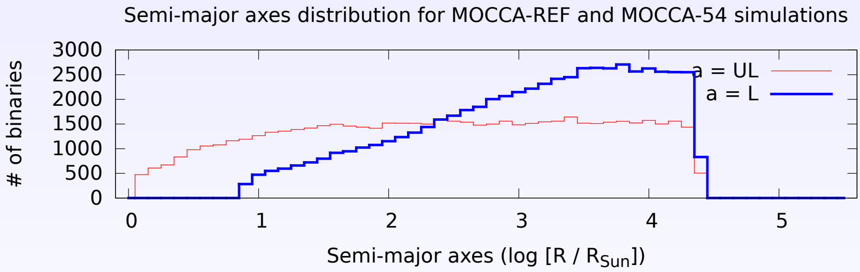


Figure: MOCCA-REF – base model; MOCCA-54 – lognormal distribution of semi-major axes

BASE model vs. lognormal semi-major axes

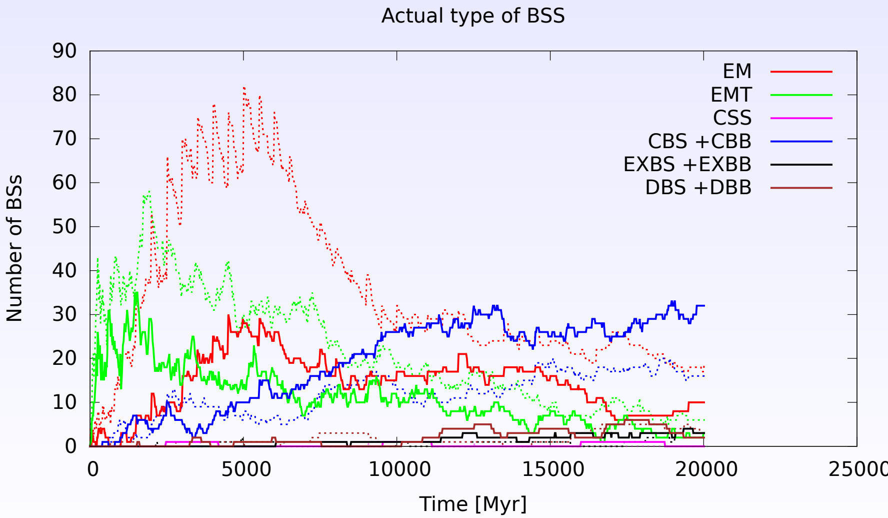


Figure: EM, EMT number ↘. CBS+CBB number ↗

- EM, EMT number $\searrow$
  - there are essentially less compact binaries to create EM and EMT BSs
- CBS+CBB number $\nearrow$
  - more dynamical interactions for wider binaries from the lognormal distribution of semi-major axes
  - many of them are just fly-by interactions: semi-major axes are not changed but eccentricities are
  - eccentricities raise to such values (close to 1.0) that a collision is detected

BASE model vs. Kroupa (1995)

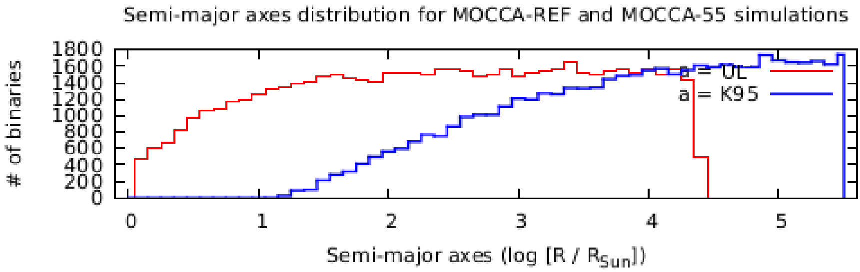


Figure: MOCCA-REF – base model; MOCCA-55 – Kroupa (1995)

BASE model vs. Kroupa (1995)

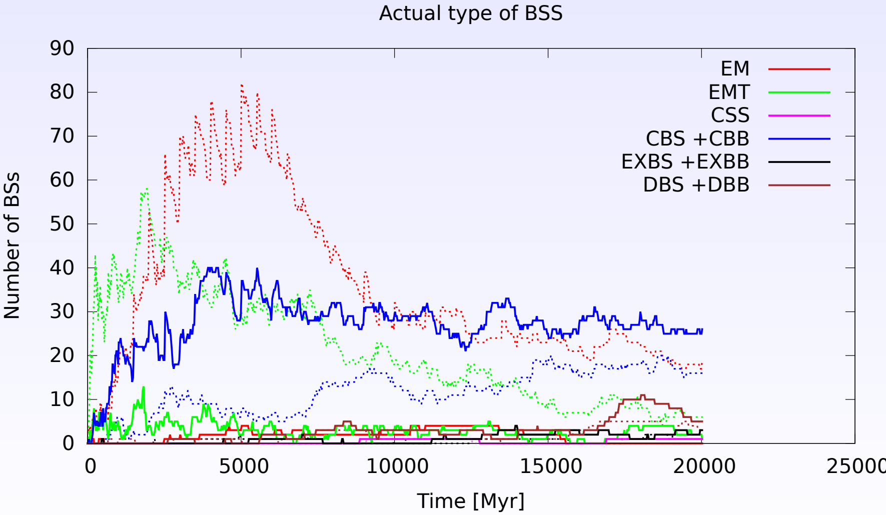


Figure: EM, EMT number not significant; CBS+CBB number ↗

Different concentrations

BASE model vs. $c = r_{tid}/r_h$ = 60 ($r_h = 6.9$ vs. 1.7 [pc])

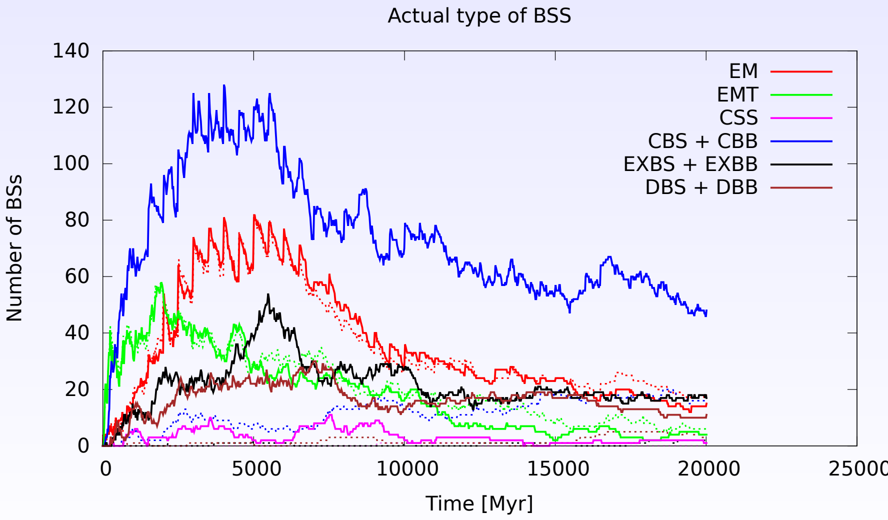


Figure: EM, EMT number essentially not changed (unperturbed primordial binaries); CBS+CBB number ↗↗↗

Bimodal spatial distribution of BSs

A few facts…

Bimodal spatial distribution

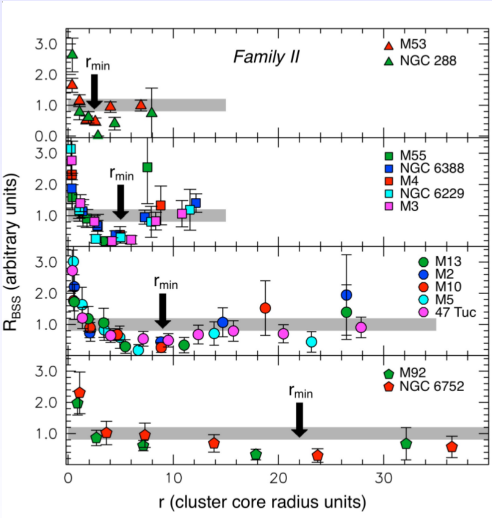


Figure: Bimodal spatial distributions for selected star clusters, Ferraro et al. (2012)

- **maximum** at the center of the cluster, **clear-cut dip** in the intermediate region and **again rise** of BSS in the outer region of the cluster (but lower than the central value)
- bimodality, if any, it is present for star clusters with various masses and concentrations

Bimodal spatial distribution – theories

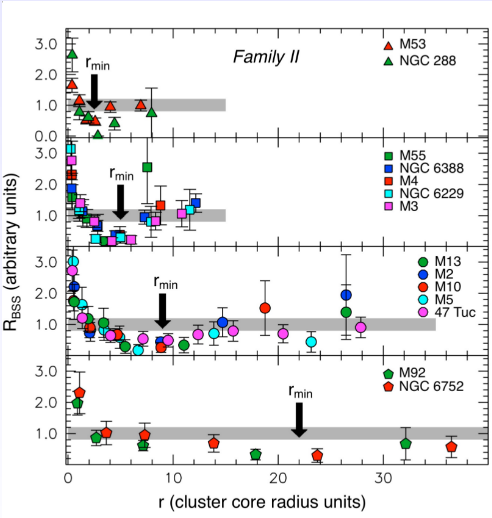


Figure: Bimodal spatial distribution for selected star clusters, Ferraro et al. (2012)

- Mappeli (2004, 2006) – the leading theory today
  - **long-term effect of dynamical friction** acting on the cluster binary population since the early stages of cluster evolution

Flat and monotonic spatial distributions

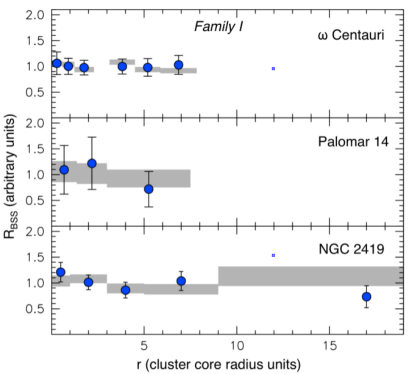


Figure: Examples of flat spatial distributions

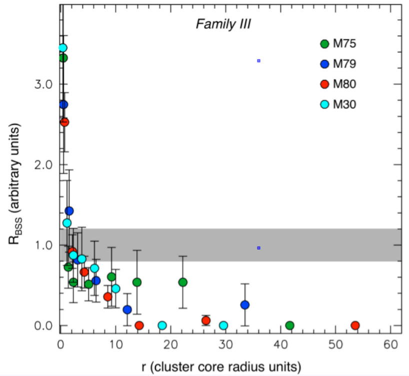


Figure: Examples of unimodal spatial distributions

Bimodal spatial distribution of BSs

How accurate is the „dynamical clock”?

The r_{avoid} drift for simplified N-body simulation

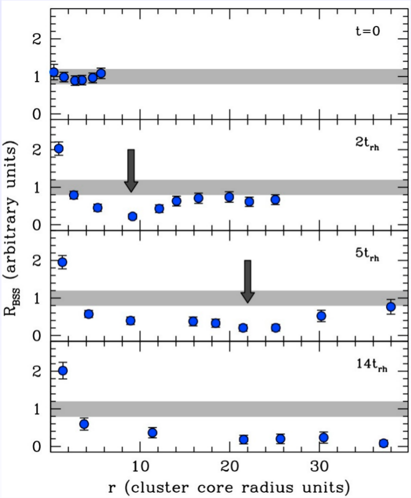


Figure: Ferraro's N-body simulation (Ferraro et al. 2012)

- simplified simulation with: 89% MS, 10% RGB and 1% BSs
- drift of the r_{avoid} with time

N-body simulation with the drift of the r_{avoid}

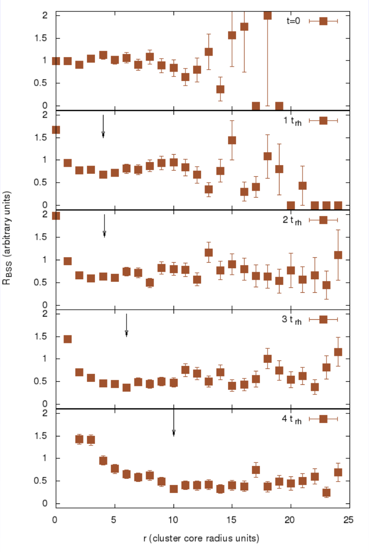
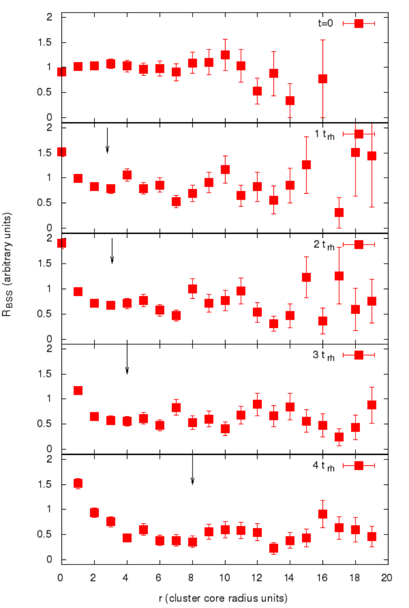


Figure: N-body simulations run by Douglas Heggie

- **N-body** simulation with the same initial conditions as from Ferraro et al. (2012)
- drift of the r_{avoid} with time visible too, but:
  - errors are larger
  - dip around r_{avoid} is smaller
  - constant drop of R_{BSS} in outside region

MOCCA simulation with the drift of the r_{avoid}



- **MOCCA** simulation with the same initial conditions as from Ferraro et al. (2012)
- drift of the r_{avoid} similar to the N-body one

N-body noise of the bins

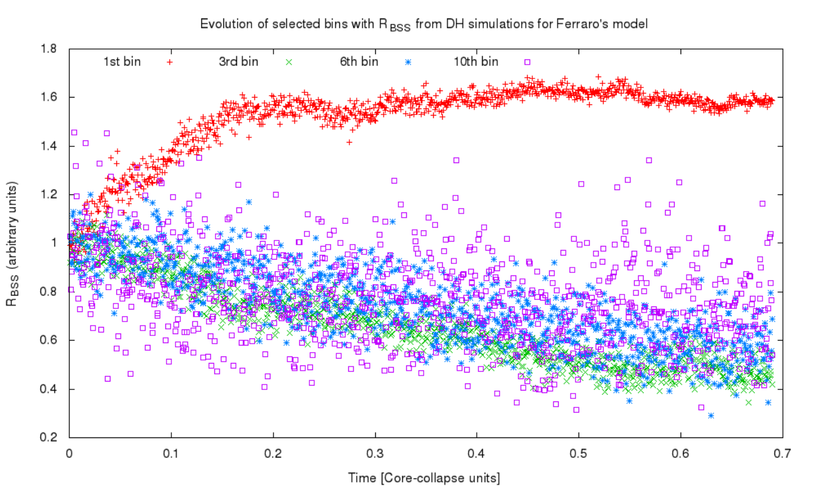


Figure: 1st, 3rd, 6th and 10th bin for N-body simulation showing large noise

MOCCA noise of the bins

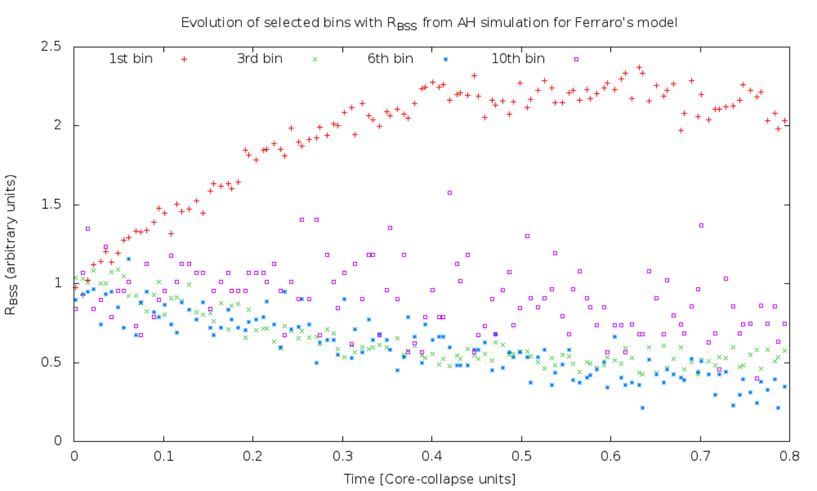


Figure: 1st, 3rd, 6th and 10th bin for MOCCA simulation showing large noise

N-body vs. MOCCA

- MOCCA agrees with N-body
- MOCCA is a proper tool to study the BSs movement in the GCs
  - ... one can proceed to the real size GCs
- there is a LARGE noise while looking for the bimodal spatial distribution

Bimodal spatial distribution of BSs for real size GCs

Real size GCs $>$ 100k stars

MOCCA, 600k, $r_{tid} = 55$, $c = 20$

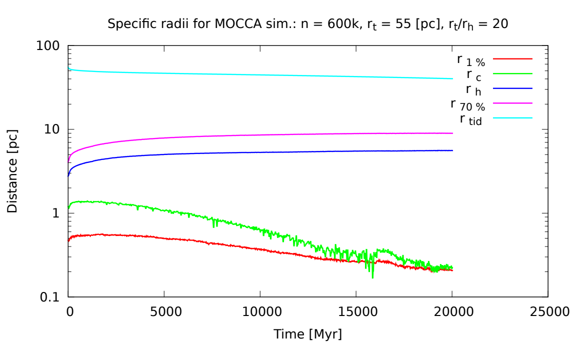


Figure: Specific radii like core radius, half-mass radius etc.

- MOCCA simulation for 600k stars, concentration $r_{tid}/r_h = 20.0$, $r_{tid} = 55$ [pc]
- fast evolving GC – radii change significantly for the whole GC
- half-mass relaxation time is „short"

MOCCA, 600k, $r_{tid} = 55$, $c = 20$

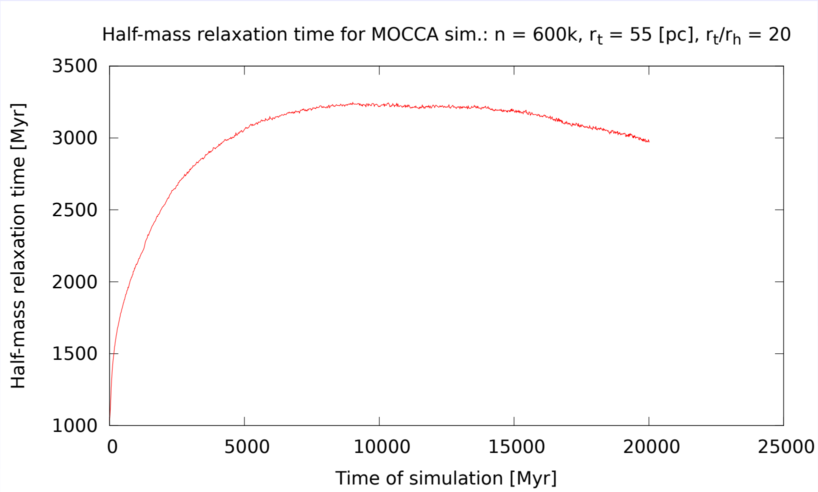
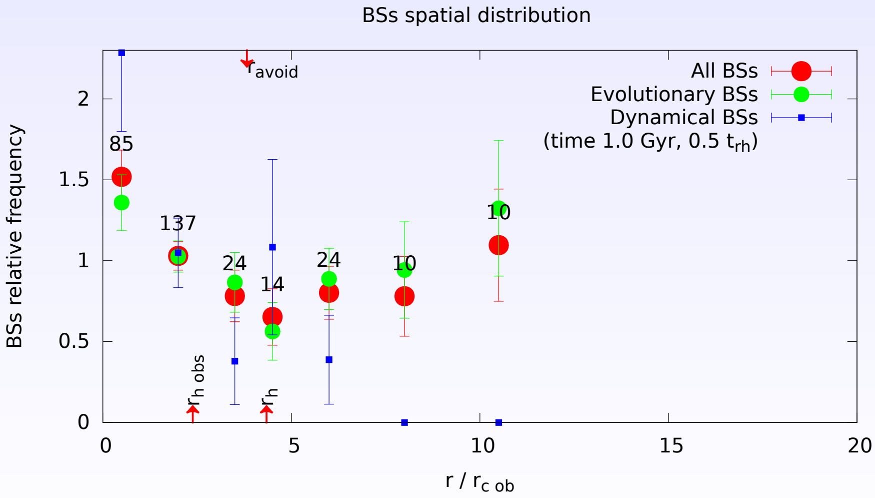
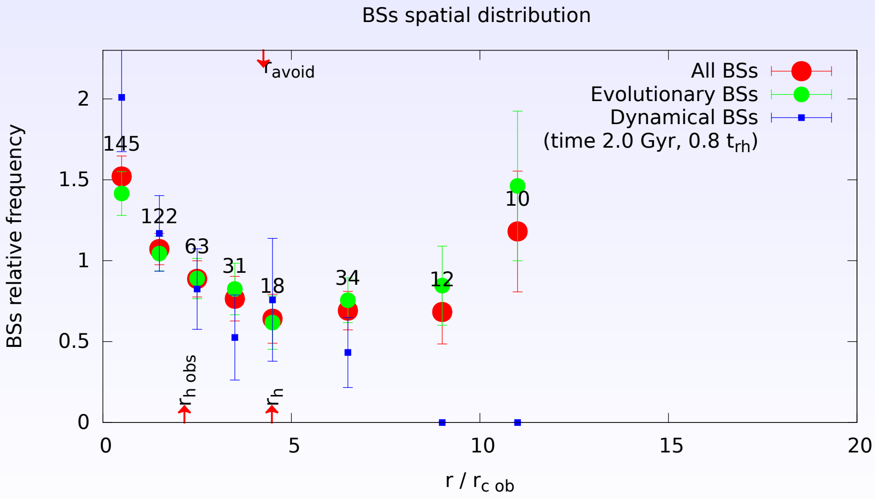


Figure: Half-mass relaxation time

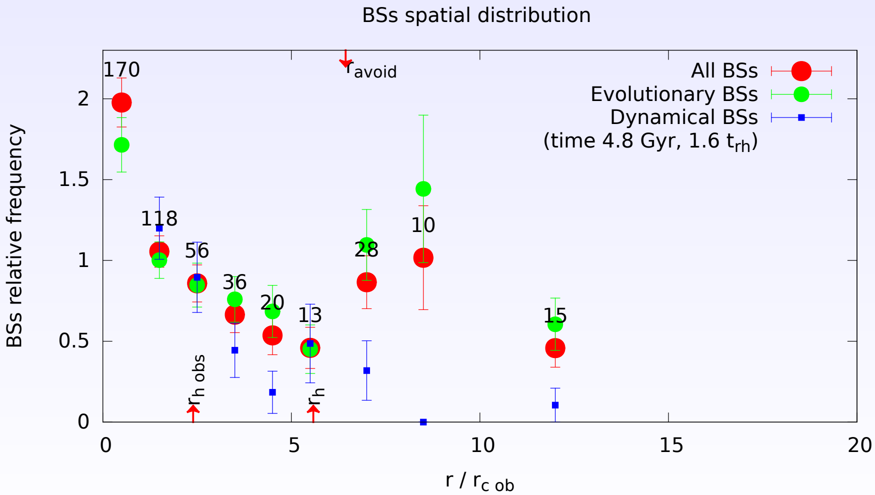
MOCCA, 600k, $r_{tid} = 55$, $c = 20$, $T = 1.0$ Gyr



MOCCA, 600k, $r_{tid} = 55$, $c = 20$, $T = 2.0$ Gyr



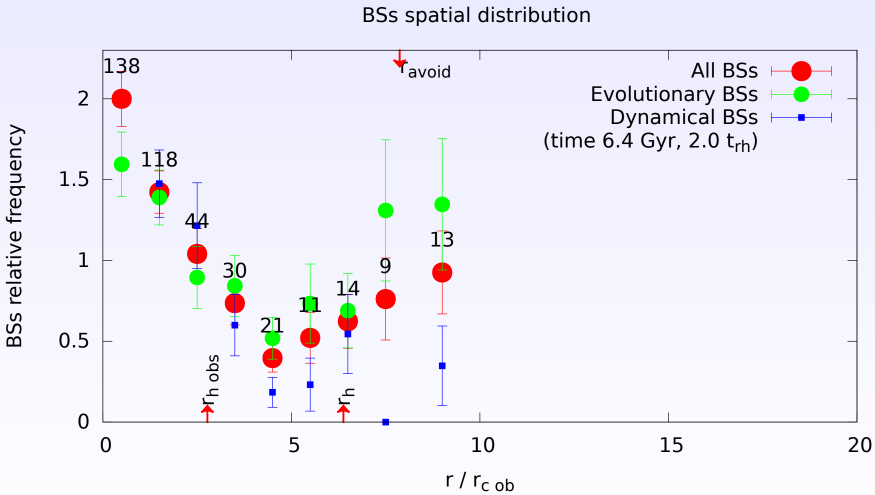
MOCCA, 600k, $r_{tid} = 55$, $c = 20$, $T = 4.8$ Gyr



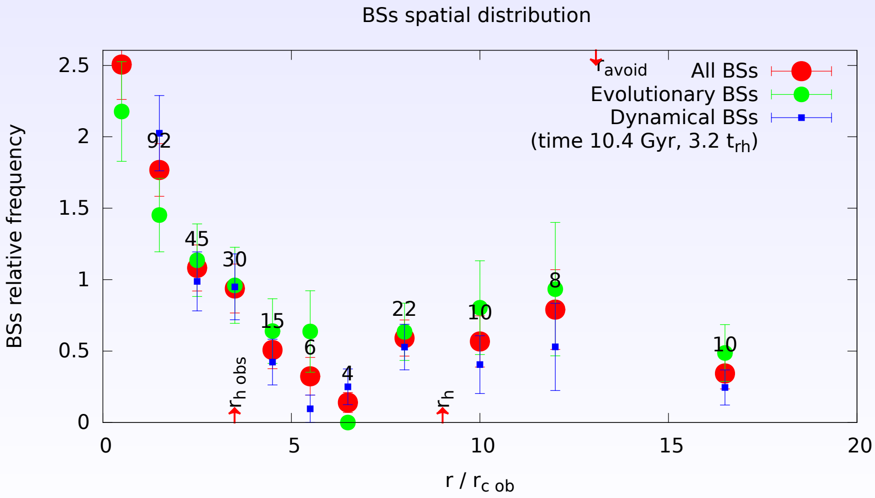
But there are problems

r_{avoid} goes out of sync with the apparent minimum after $\sim 2t_{rh}$

MOCCA, 600k, $r_{tid} = 55$, $c = 20$, $T = 6.4$ Gyr



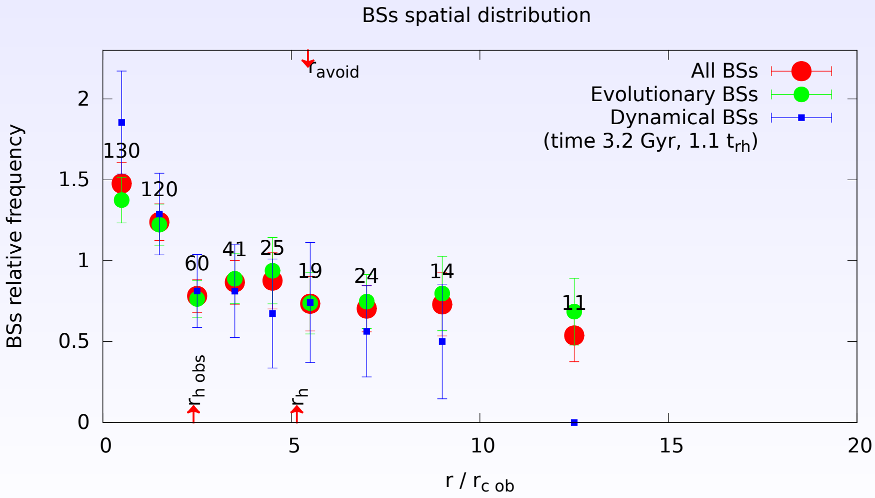
MOCCA, 600k, $r_{tid} = 55$, $c = 20$, $T = 10.4$ Gyr



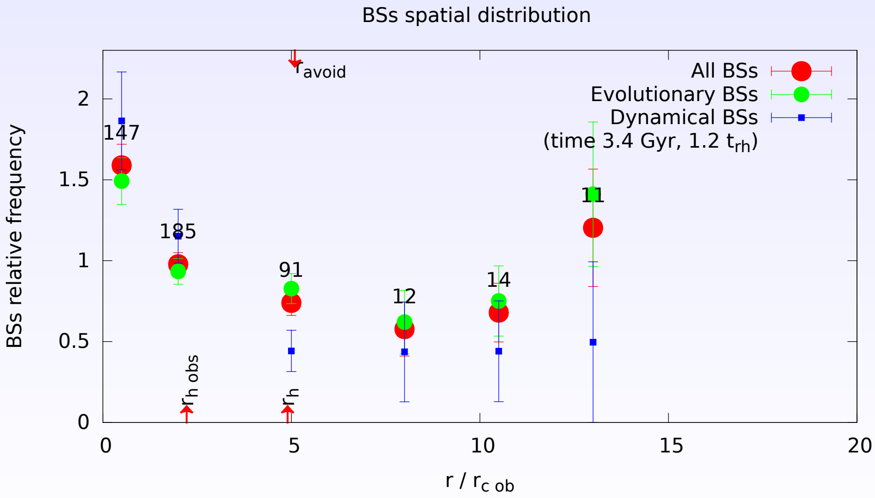
Bimodal spatial distribution is very transient

It appears and vanishes all the time...

MOCCA, 600k, $r_{tid} = 55$, $c = 20$, $T = 3.2$ Gyr



NEXT snapshot $+200$ Myrs, $T = 3.4$ Gyr



Transientness of the bimodal distribution

- the number of clear signs of the bimodal distribution was observed only in 13 out of 53 snapshots between time 1 Gyr and 11.6 Gyr
- 25% chance to see a bimodality for this model

Possible observational implication of the transientness of the bimodality

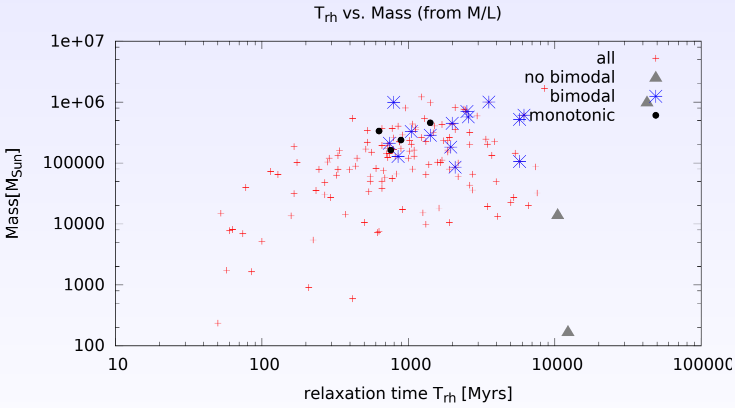


Figure: Bimodal spatial distributions for real star clusters (Harris catalogue)

The case of NGC 6388

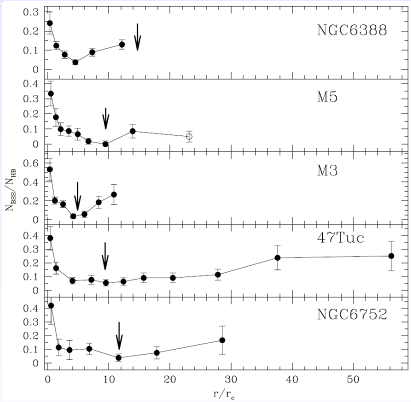
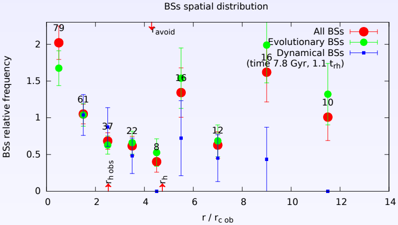


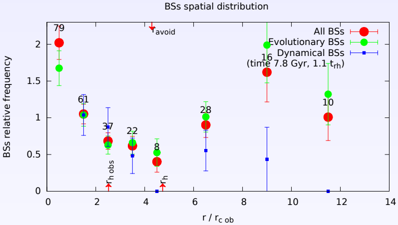
Figure: Spatial distribution of BSs for five globular clusters: NGC 6388, M5, M3, 47 Tuc and NGC 6752 Lanzoni (2007).

- all GCs have a clear bimodal spatial distribution
- the arrows represents the calculated radius of avoidance.
- in the case of NGC 6388 its r_{avoid} does not correspond to the dip in the number of BSs which is around $5r/r_c$
- it suggests that NGC 6388 is a dynamically old GC – not dynamically younger as it is stated by Dalessandro (2008)

The way of binning is very important

Combining two separate bins into larger one





Summary

- the initial **semi-major** axes distribution is **crucial**
  - large number of compact binaries $\rightarrow$ large number of EM and EMT
  - a very unexpected results:
    - increase of the dynamical BSs for semi-major axes distributions with wider orbits
  - but still, there is a strong need to distinguish evolutionary BSs from the dynamical ones
- higher concentrations do not seem to change evolutionary BSs population
  - it gives additional „confidence" that **EM, EMT** are a result of unperturbed evolution of the **primordial binaries**

Summary

- „dynamical clock” - works!
  - ..., but it seems it works only „in the morning”
- bimodality is a feature of BSs in GCs
  - ..., but very transient one
- bimodality is present even for old, large GCs (dynamically young)
  - ..., but very close to the GC's center
  - $\Rightarrow$ it is not a feature characteristic only for dynamically old GCs


Thank you!
http://www.moccacode.net/