Channels of formation of blue stragglers with the MOCCA code

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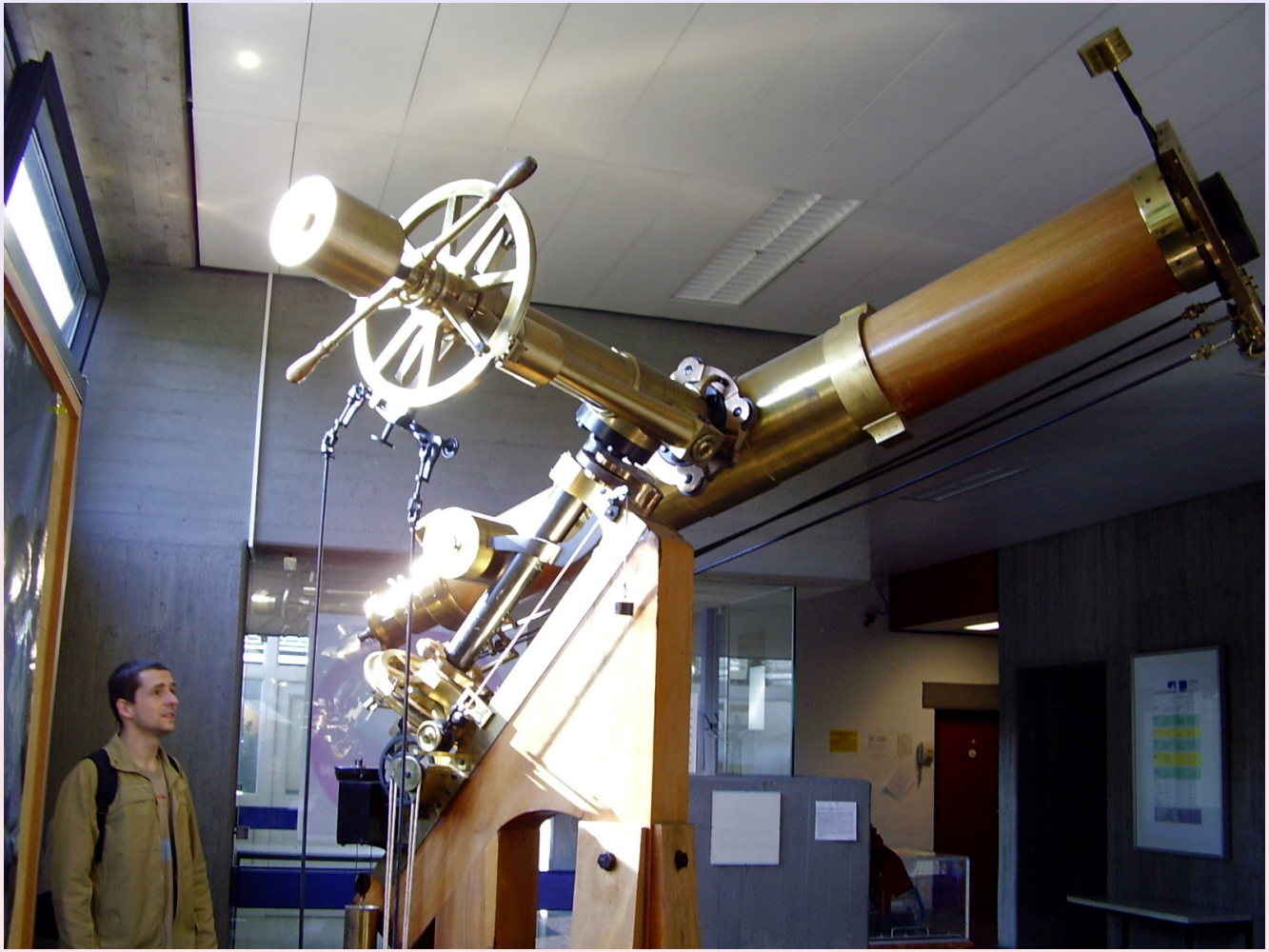
Plan

1. The MOCCA code
2. BSS properties
   - EMT, EM, CBS+CBB
   - Type changes
   - Possible induced mass transfer
3. BSS global parameters
   - BSS positions
   - BSS lifetimes and escapers
4. Summary

Plan

Everything started here...



The MOCCA code

- code for simulations of real size star clusters
- MOCCA == Monte Carlo method + Fewbody + SSE/BSE
  - spherical shells instead of stars; each shell is characterized by: mass (m), energy (E) and angular momentum (L).
  - relaxation process of a given object with all other objects in the system is approximated just by one interaction of two neighbouring shells.
- it aggres with N-body codes very well (Giersz et al. 2012)
- it scales with the star cluster masses
- it is fast(!)
- it gives basically the same amount of information as N-body codes
- it allows detail comparison with observations of exotic star cluster objects e.g. **blue stragglers**

Plan

Test model

Parameter	Description
Single stars (N_s)	80k
Binary stars (N_b)	20k
Initial model	Plummer
IMF of stars	Kroupa (1993) in the range $[0.1; 50]M_\odot$
IMF of binaries	Kroupa (1991), binary masses from 0.2 to 100 $M_\odot$
M(0)	0.602 $\times 10^5 M_\odot$
Initial r_c and r_h (observational)	0.36 pc, 0.53 pc
Initial tidal radius	35.8 pc
Concentration r_c/r_h	0.68
Binary mass ratios	Uniform (component masses as for single stars)
Binary semi-major axes	Uniform in log $2(R_1 + R_2)$ - 50 AU
Binary eccentricities	Thermal (modified by Hurley (2005))
Metallicity	0.001

Initial conditions

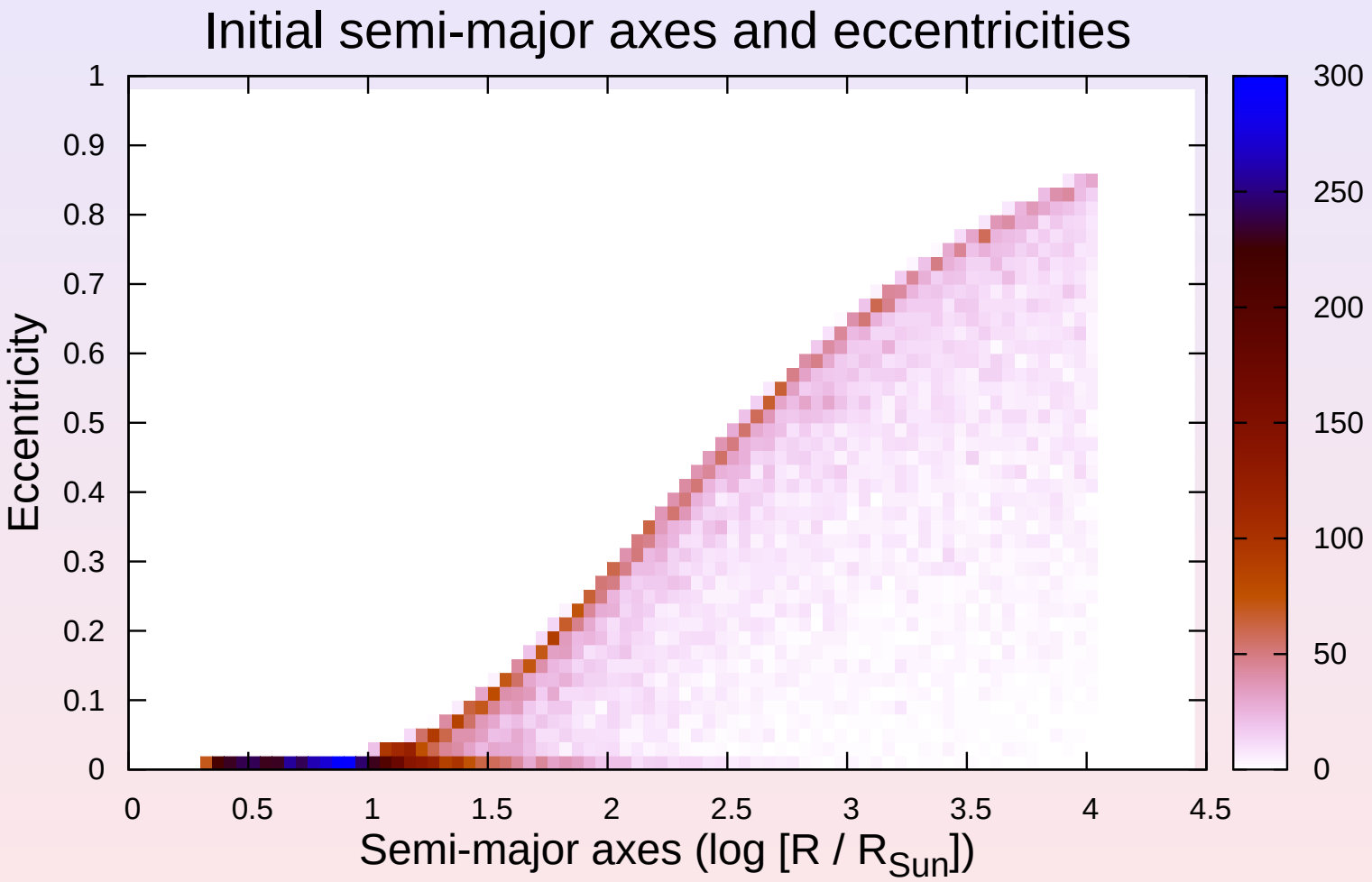
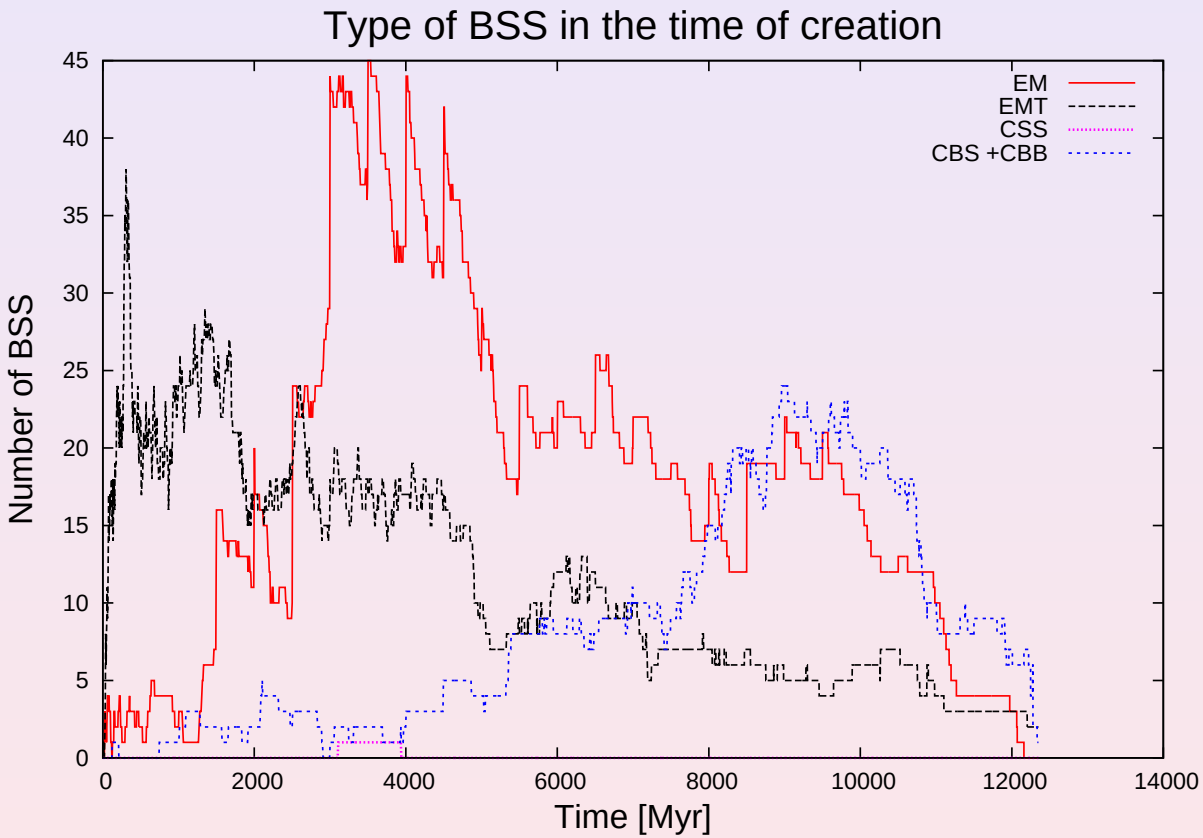


Figure : Initial eccentricities and orbital periods for binaries

Initial channels of formations of BSS



- EMT most active at the beginning
- EM peak about 3 Gyrs
- there is only one CSS
- CBS, CBB active when the core starts to collaps

Figure : Number of initial types of BSS from different channels of formation in the time of their creation

Evolution mass transfer (EMT)

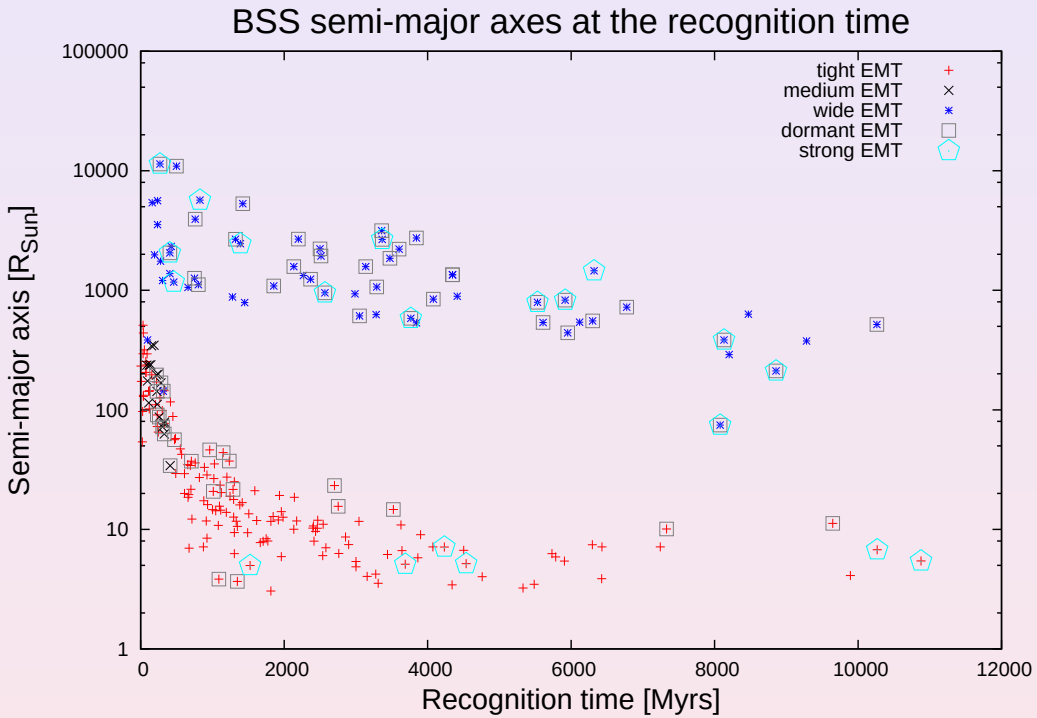


Figure : Semi-major axes for tight (red), medium (green), wide (blue), dormant and strong EMT

- two distinct formation scenarios for tight+medium and wide EMT
  - disk accretion for tight+medium EMT
  - stellar winds for wide EMT
- dormant and strong EMT are mostly wide EMT
- eccentricities circularization for tight but not for wide EMT

Evolution mass transfer (EMT)

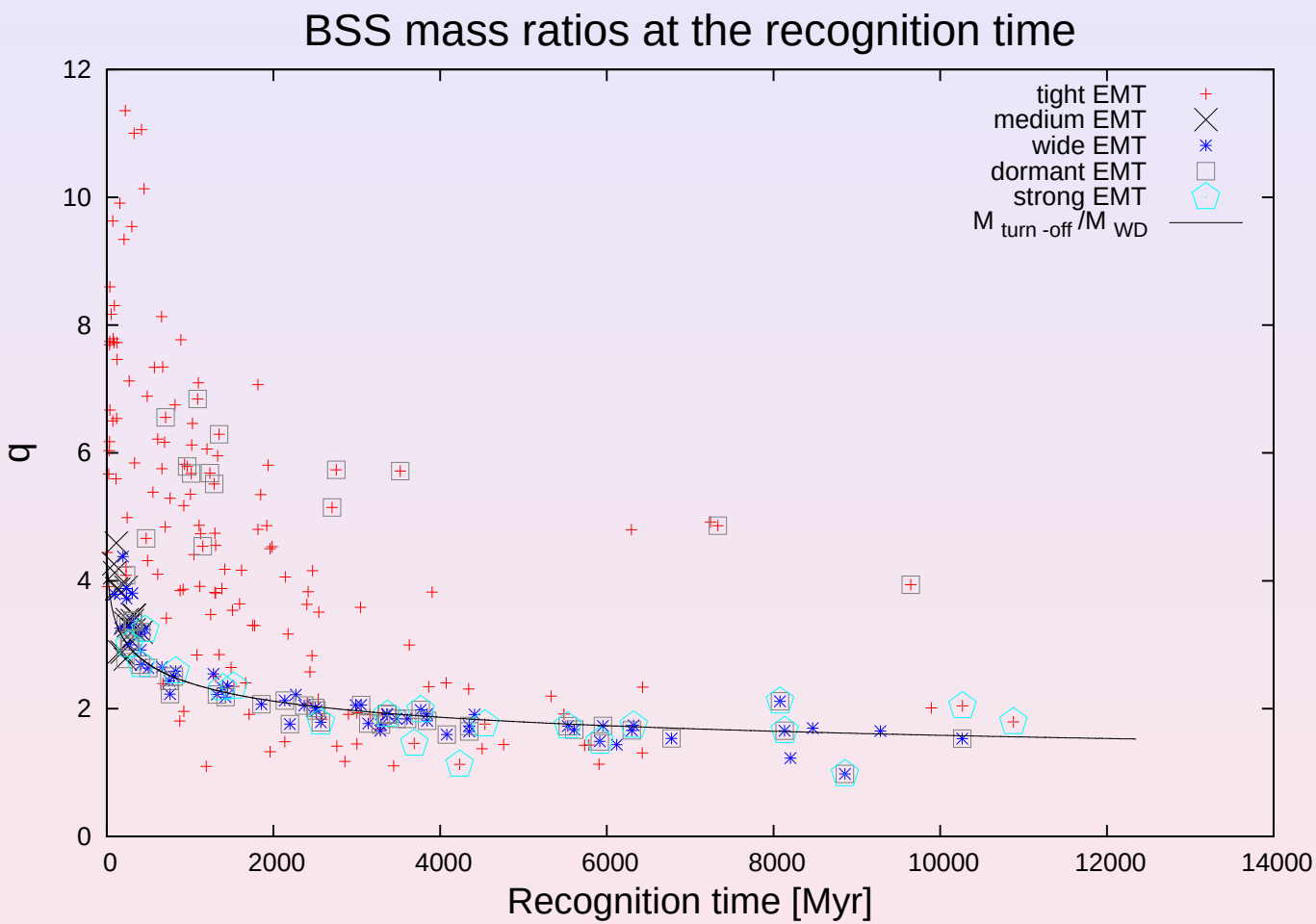
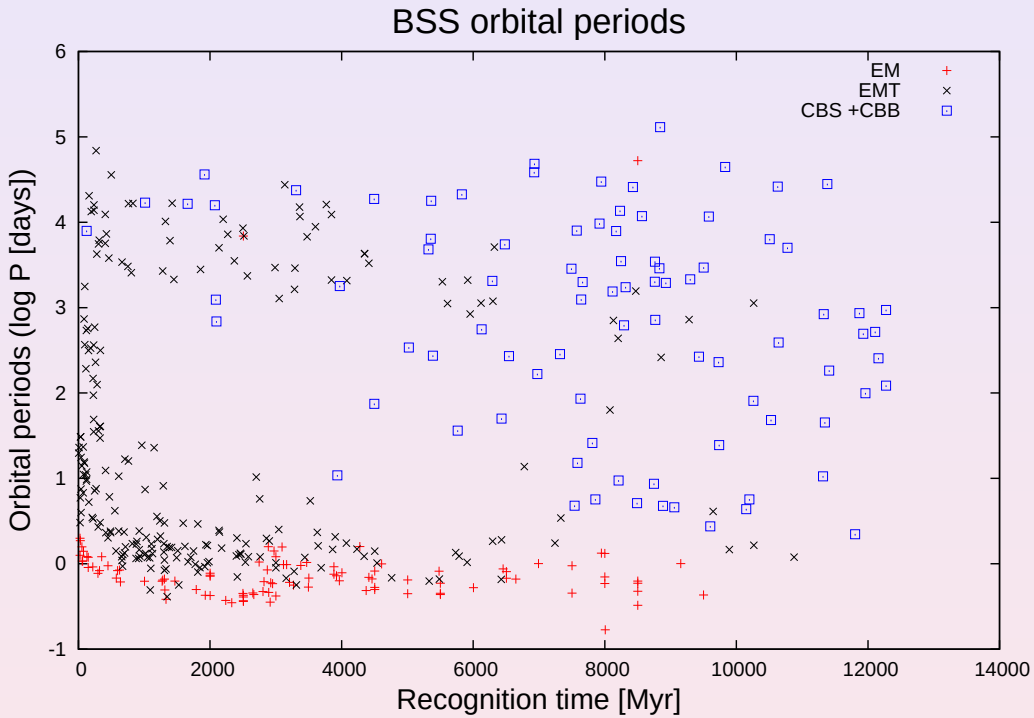


Figure : Mass ratios for tight (red), medium (green), wide (blue), dormant and strong EMT

Evolution merger (EM)

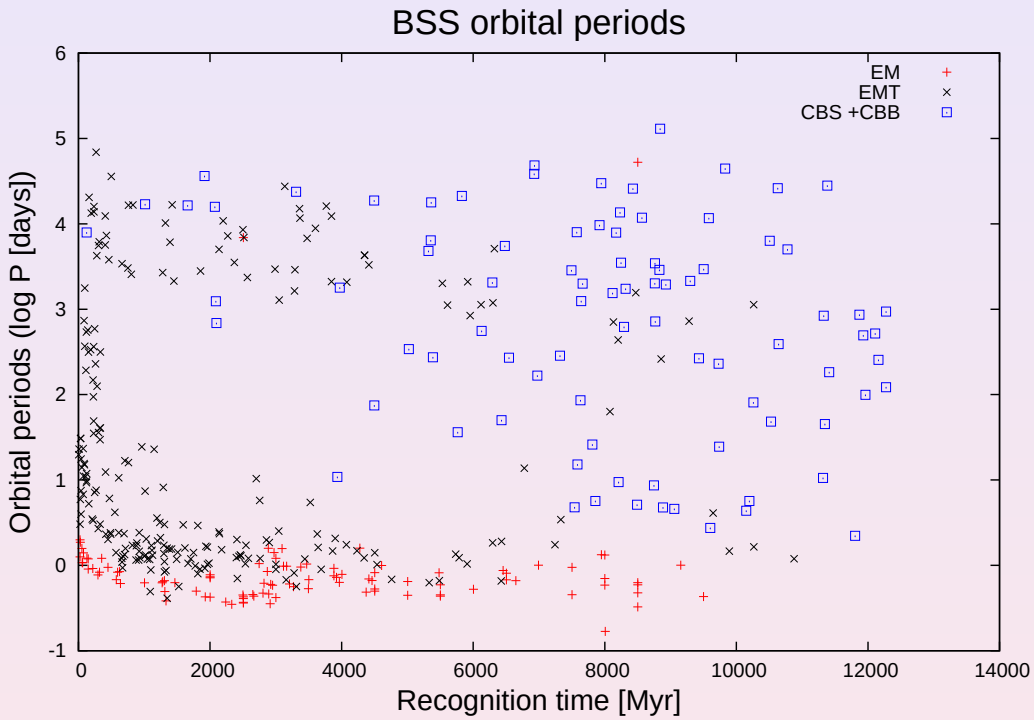


Evolution mergers (EM):

- small orbital periods for EM
- eccentricities = 0.0
- two distinct formation scenarios
  - disk accretion mainly for < 3 Gyrs
  - magnetic braking mainly for > 3 Gyrs

Figure : BSS creation channel vs. BSS orbital periods in the time of creation

Dynamical mergers CBS,CBB



Collisional BSS:

- no typical formation scenarios
- significantly more is produced when the core starts to collaps
- only wide binaries first, and after core starts to collaps also tight ones

Figure : BSS creation channel vs. BSS orbital periods in the time of creation. Creation time is in Myr and orbital period is in units of log(days)

Histogram of masses of BSS

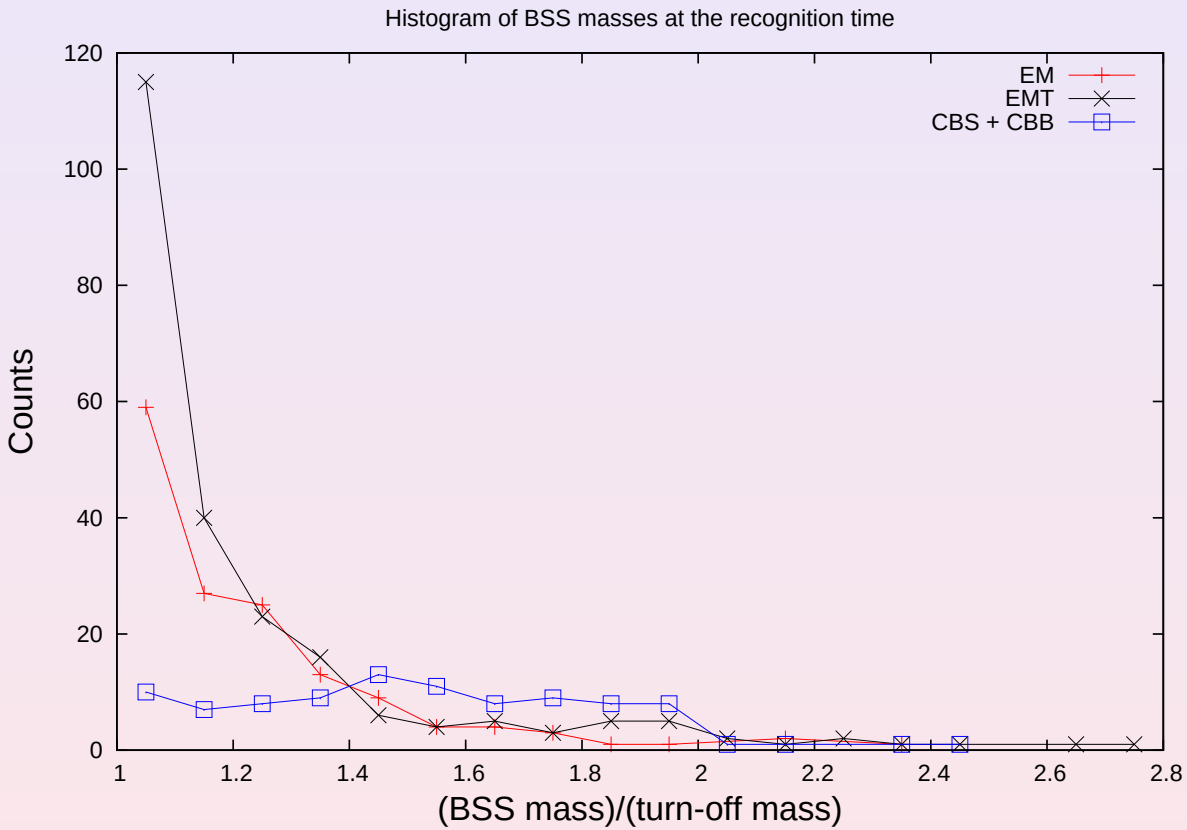
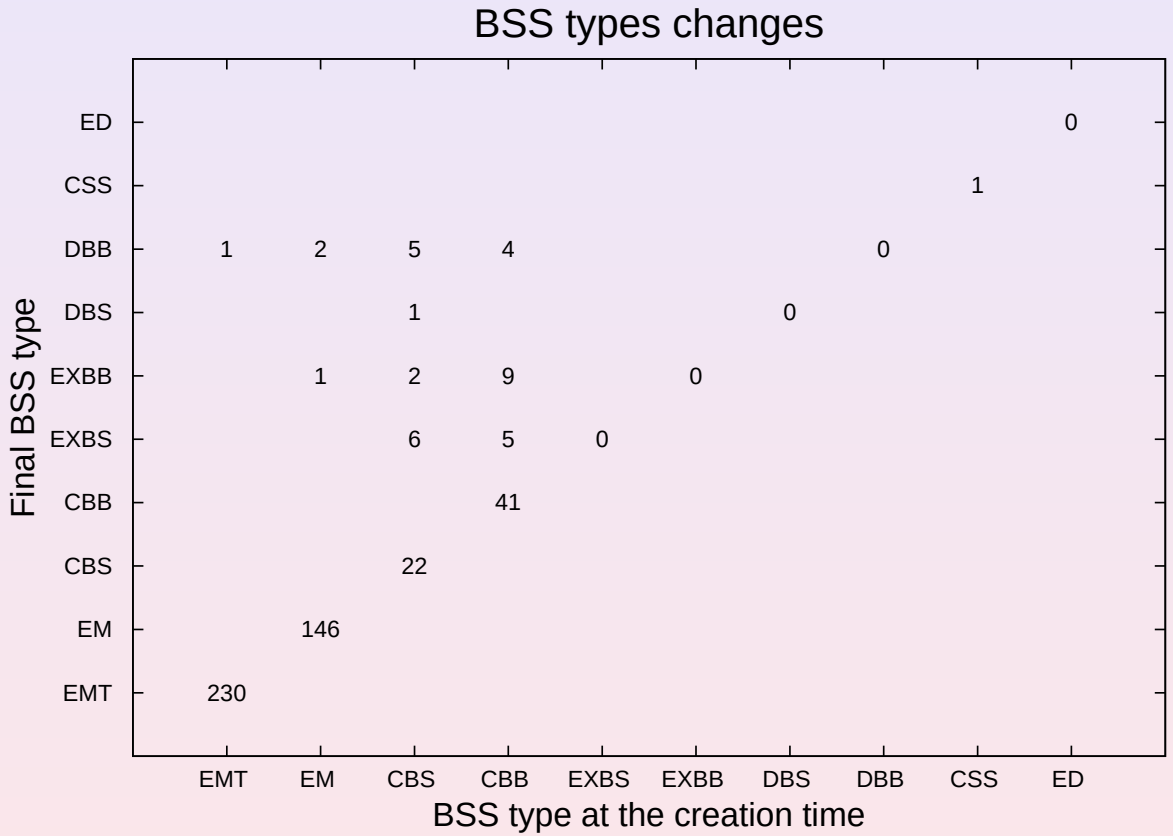


Figure : Histogram with masses of BSS divided by turn-off mass in the time of their creation for 3 most active channels of formation. Only initial BSS channels of formation are presented.

- majority of EM, EMT just slightly larger than turn-off mass
- CBS, CBB masses uniform for the whole range
- for times larger than few Gyrs EM and EMT are even closer to the turn-off mass

Type changes in numbers



- EM, EMT do not change types
  - but if they do there are some complex scenarios present
- CBS, CBB change types, especially after core starts to collaps

Figure : BSS type changes between different BSS types. Each number shows how many BSS stars changed its type from one to another

Possible induced mass transfer

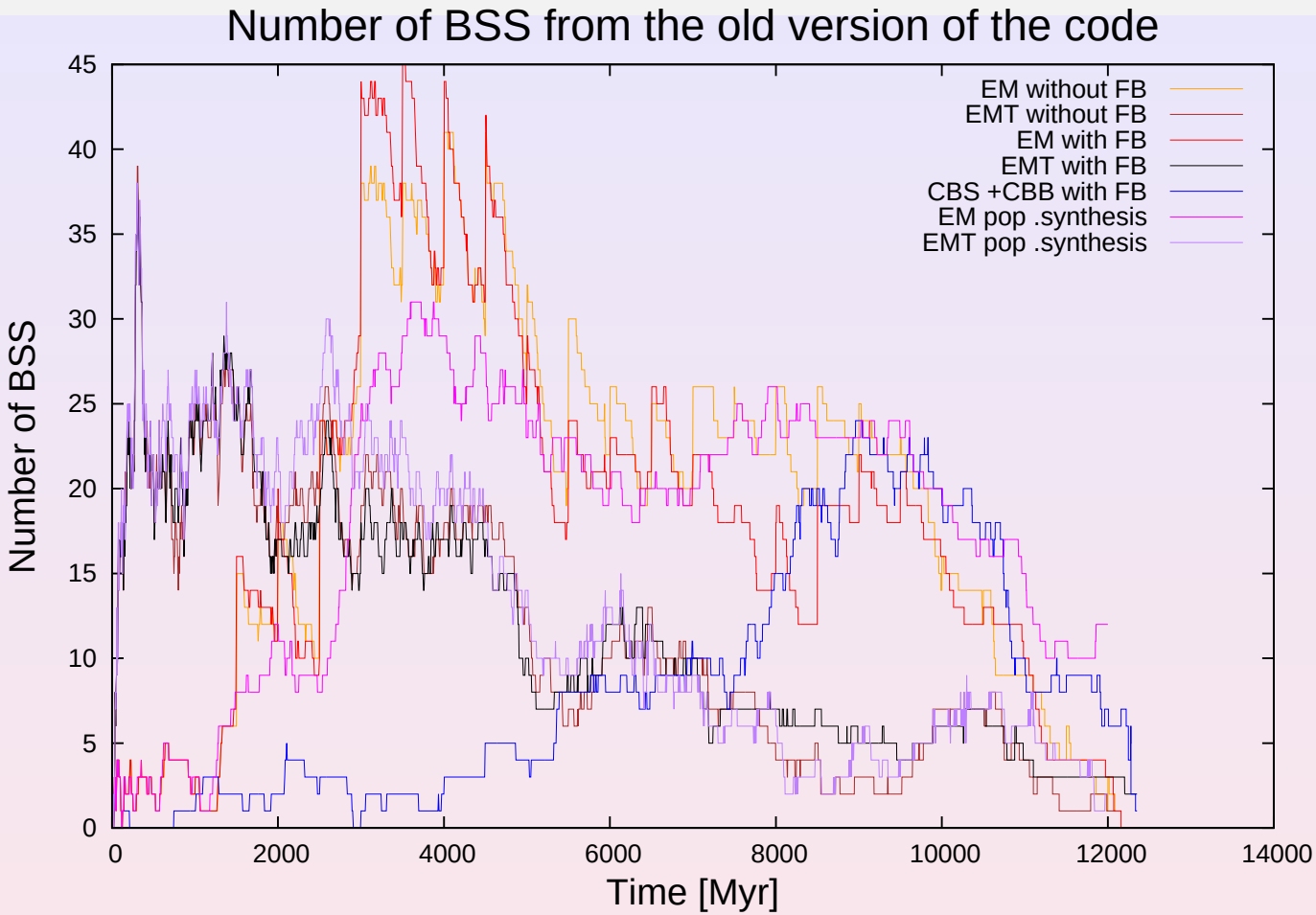
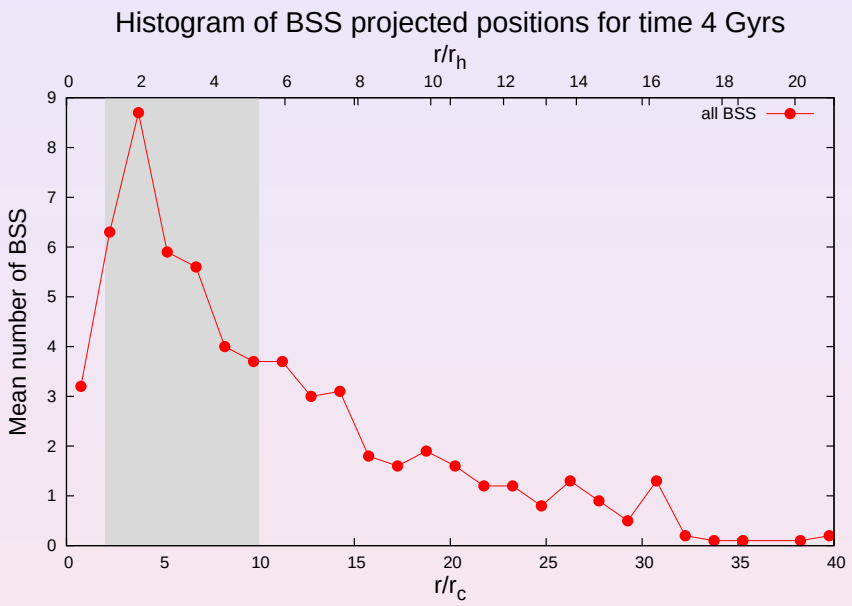


Figure : Comparison of the numbers of BSS for the test simulation with the old version of the code (without the FEWBODY code) and with the simple population synthesis (without any dynamical interactions)

Plan

BSS bimodal spatial distribution



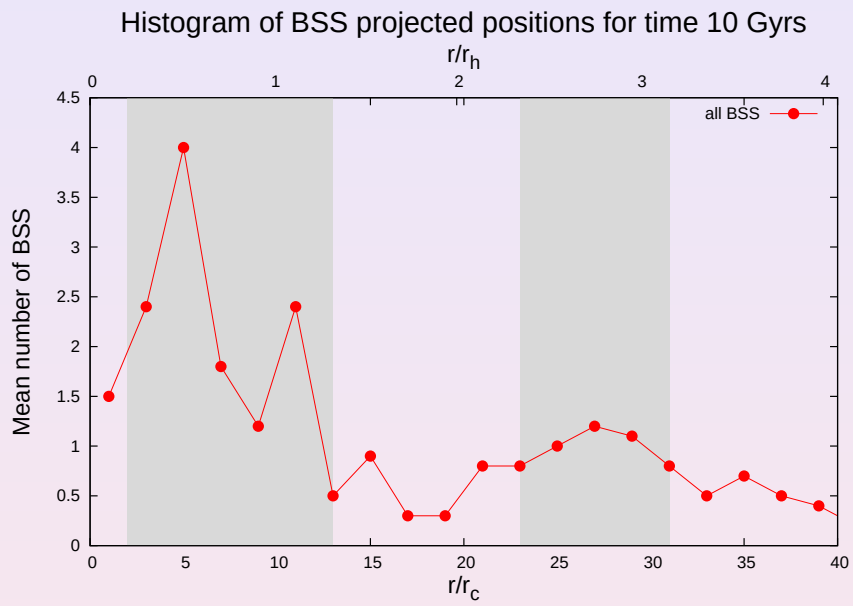
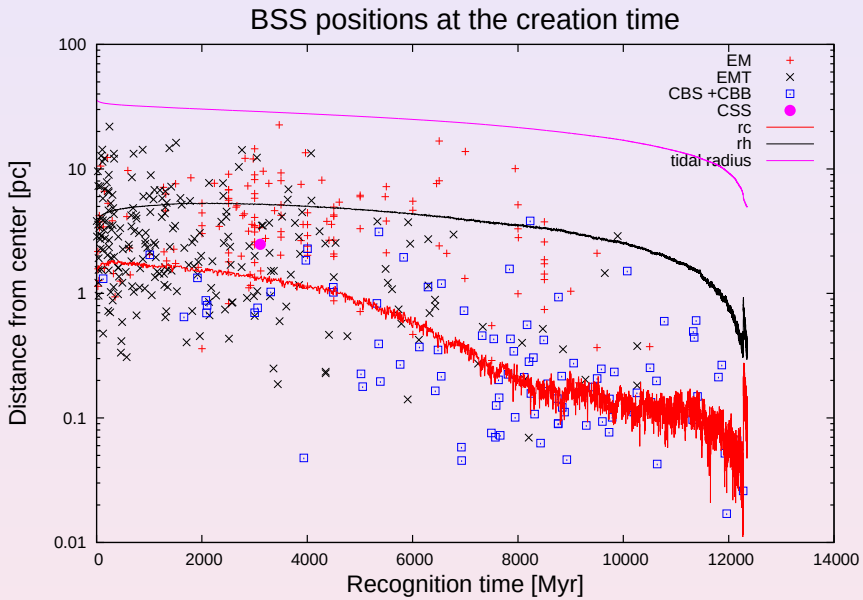


Figure : Bimodal spatial distribution of BSS. At the time 4 Gyrs bimodality is not visible yet, but at the time 10 Gyrs weak bimodality is visible • Ferraro at al. (1993, 1997) found bimodality for M55, Zaggia et al. 1997 for M3 • NGC 2419 has flat BSS distribution (Dalessandro et al. 2008)

BSS initial and final positions



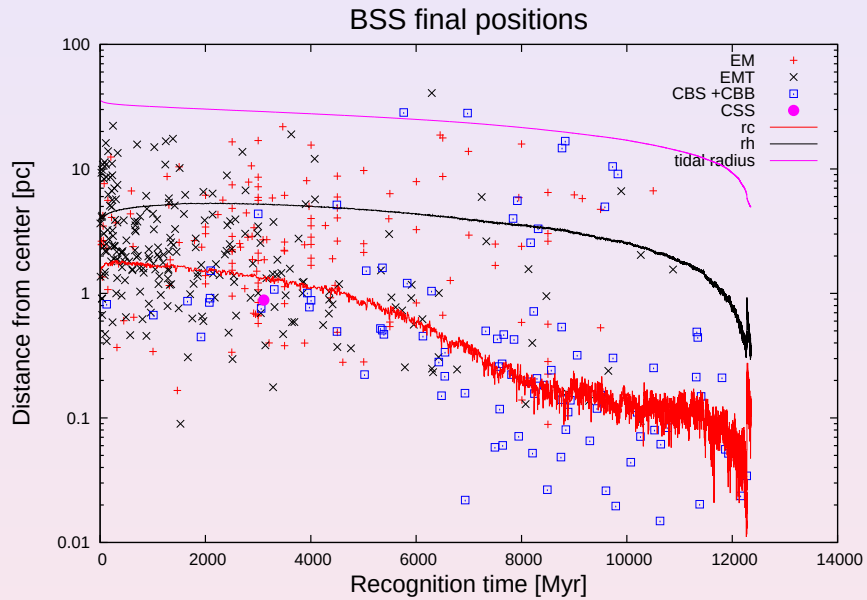
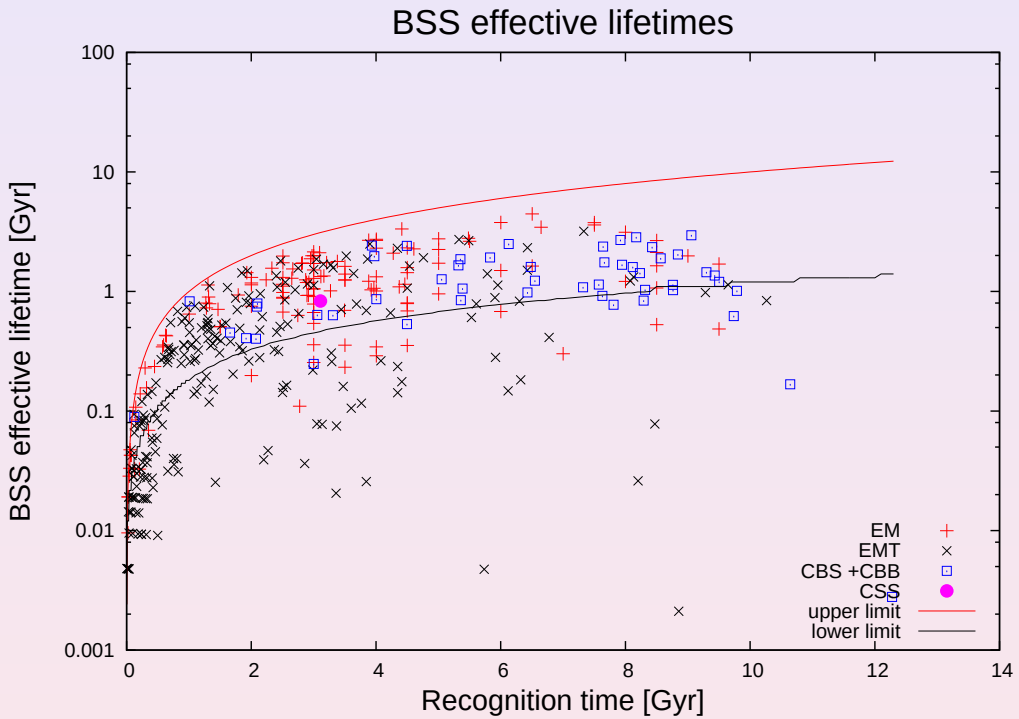


Figure : Initial and final positions of the BSS. EM, EMT roughly in the same place. CBS+CBB more scattered

BSS lifetimes (not fixed)



- lifetimes = time between detection of the BSS and time when star stopped to be a BSS
- two boundary lines shows the min. and max. lifetimes for BSS
- many of BSS are below min. boundary $\rightarrow$ dormant BSS
- most dormant BSS are wide EMT

Figure : Lifetimes of BSS vs. their creation times for different initial channels of formations

BSS lifetimes (fixed for dormant BSS)

- fixed lifetime = time between the last merger event (all channels except EMT) or last mass transfer (for EMT) and time when star stopped to be a BSS
- many BSS fit between boundary lines

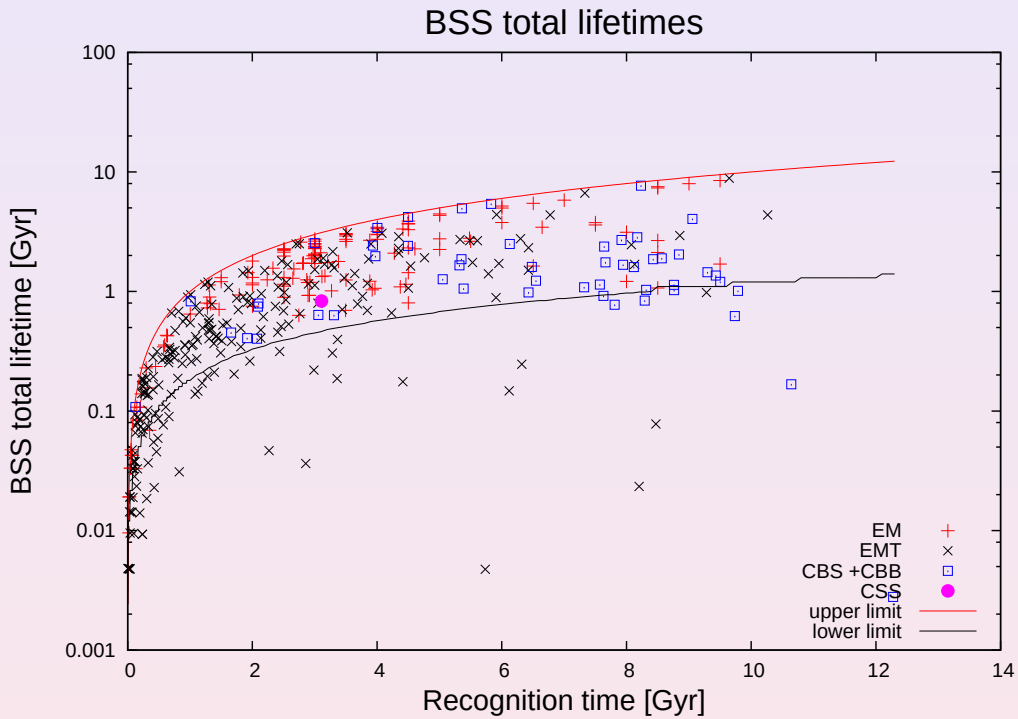


Figure : Overall lifetimes of BSS vs. their creation times for different initial channels of formations

BSS escapers

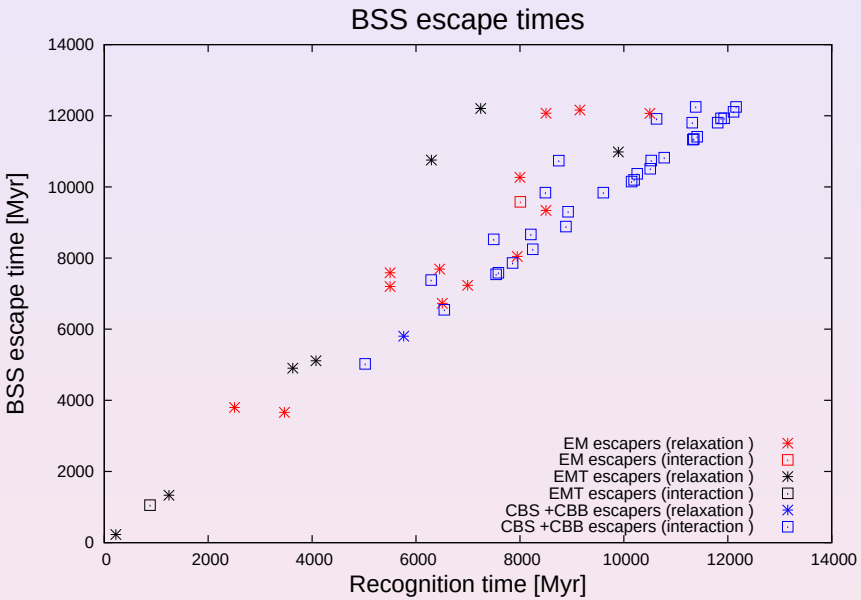


Figure : Escape time for BSS vs. creation times of BSS for different channels of formations. There are two escape reasons: relaxation or dynamical interaction.

- only 3% of EMT escaped as BSS
- only 13% of EM escaped as BSS
- 43% of CBS+CBB escaped as BSS, after core collapse 60%
- EM and EMT escaped due to relaxation mainly (slow escapers)
- allmost all CBS+CBB escaped due to interactions (fast escapers)
- one can search for BSS in tidal tails, and in the Galaxy's halo and bulge (Bragaglia et al. 2005; Fuhrmann et al. 2011; Clarkson et al. 2011)

The future projects

- huge survey
  - whole mesh of possible initial conditions
  - automatic search for inital conditions
- hierarchical systems
  - additional channel of BSS formation

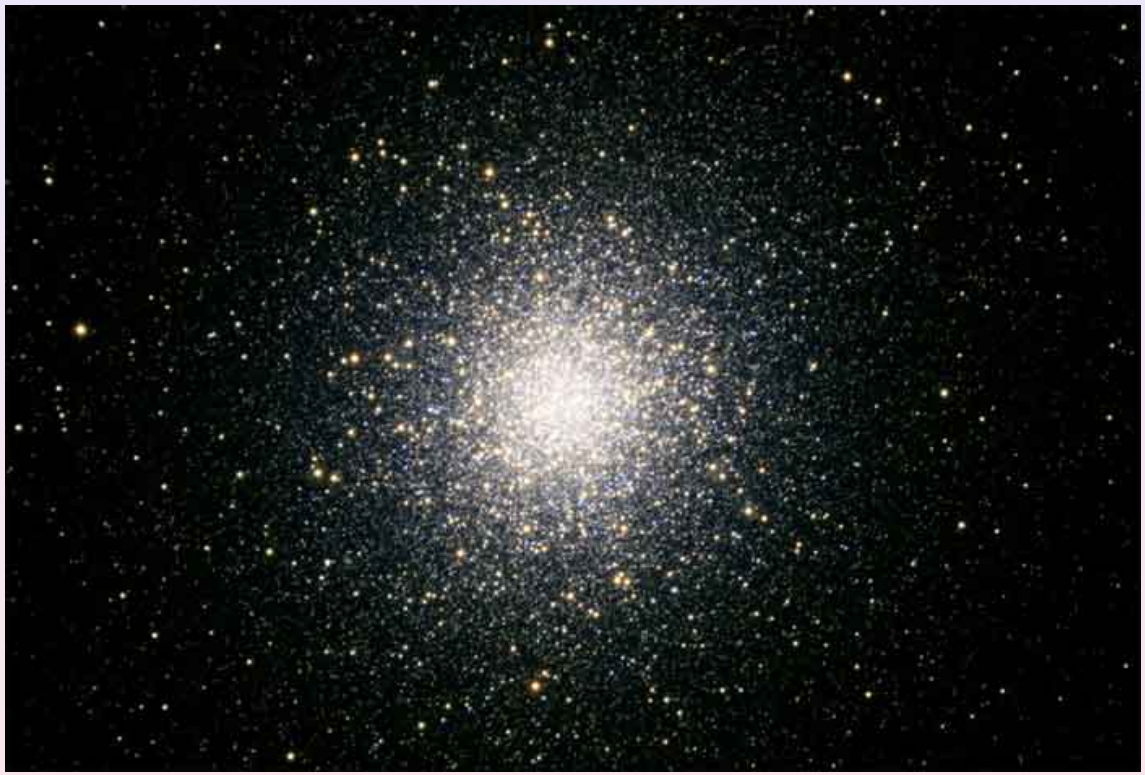


Figure : M13 (credits: NASA)

Summary

The MOCCA code:

- very advance code for star cluser evolution
- fast
- reliable
- suitable to follow the evolution of peculiar objects: CVs, BHs, BSS...

Blue stragglers:

- population of BSS strongly depends on the initial conditions
- BSS are created in binaries (only one BSS created from star-star collision)
- BSS may be a good tracers of dynamical state of the star cluster (core collapse)

Thank you!

Thank you!

Please, do not hesitate to ask me questions :)