MOCCA CODE FOR STAR CLUSTER SIMULATIONS - I. BLUE STRAGGLERS, FIRST RESULTS

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ABSTRACT

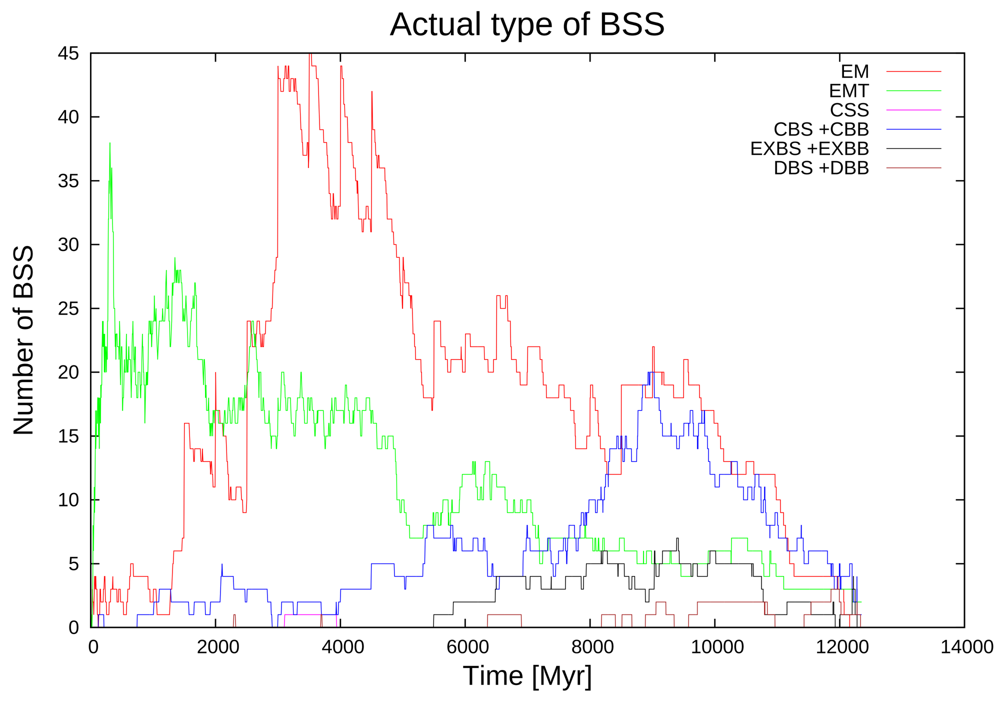
We introduce an improved code for simulations of star clusters, called MOCCA, which stands for MOnte Carlo Cluster simulAtor. It combines the Monte Carlo method for star cluster evolution and the *Fewbody* code to perform scattering experiments. The MOCCA code is currently one of the most advanced codes for simulating real size star clusters. It follows the star cluster evolution closely to N-body codes but is much faster. We show that the MOCCA code is able to follow the evolution of BSS with details. It is a suitable tool to perform full scale evolution of real star clusters and detail comparison with observations of exotic star cluster objects like Blue Stragglers Stars (BSS).

This paper presents first results of our larger project about properties of BSS in star clusters. By studying this type of stars one can get important constrains on a link between the stellar and dynamical evolution of star clusters. We discuss first results concerning BSS for an arbitrary chosen test model. We investigate properties of BSS which characterize different channels of formation like masses, semi-major axes, eccentricities, and orbital periods. We show how BSS from different channels change their types, and discuss initial and final positions of BSS, their bimodal distribution in the star cluster, lifetimes and more.

TEST MODEL

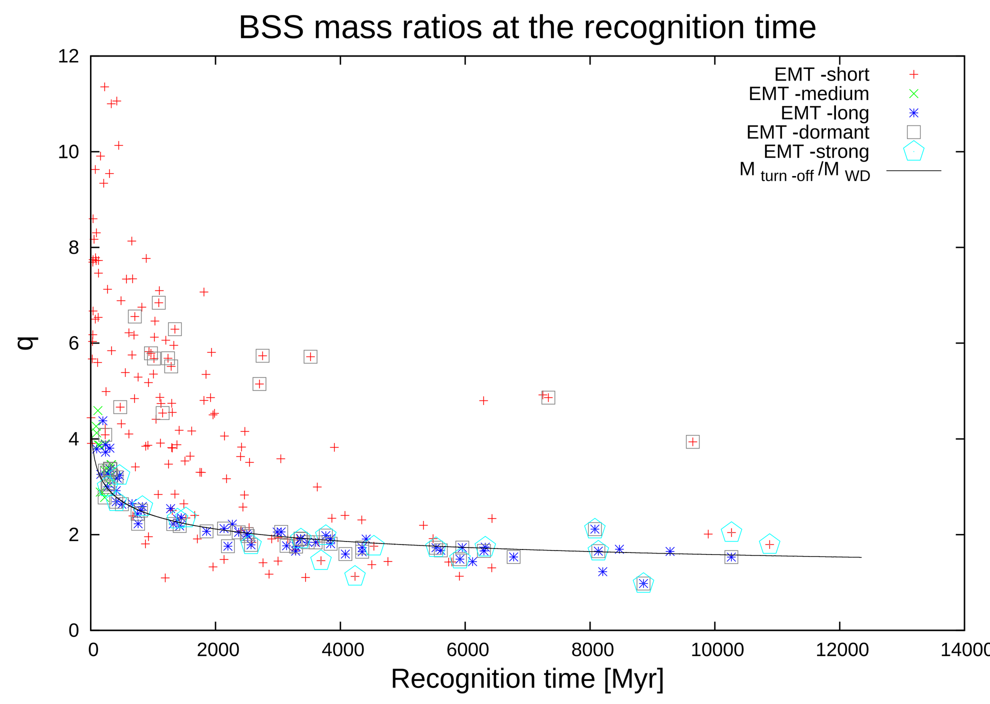
- 80k single and 20k binary stars
- Plummer model
- $r_c l$ = 0.36 pc, $r_h l$ = 0.53 pc, r_{tidal} = 35.8 pc
- metallicity 0.001

CHANNELS OF FORMATION OF BSS



- evolutionary: EM - Evolutionary Merger; EMT - Evolutionary Mass Transfer; ED - Evolutionary Dissolution
- dynamical: CSS - Collision Single-Single; CBS/B - Collision Binary-Single/Binary
- type changes: EXBS/B - Exchange Binary-Single/Binary; DBS/B - Dissolution Binary-Single/Binary

EVOLUTIONARY MASS TRANSFER (EMT)

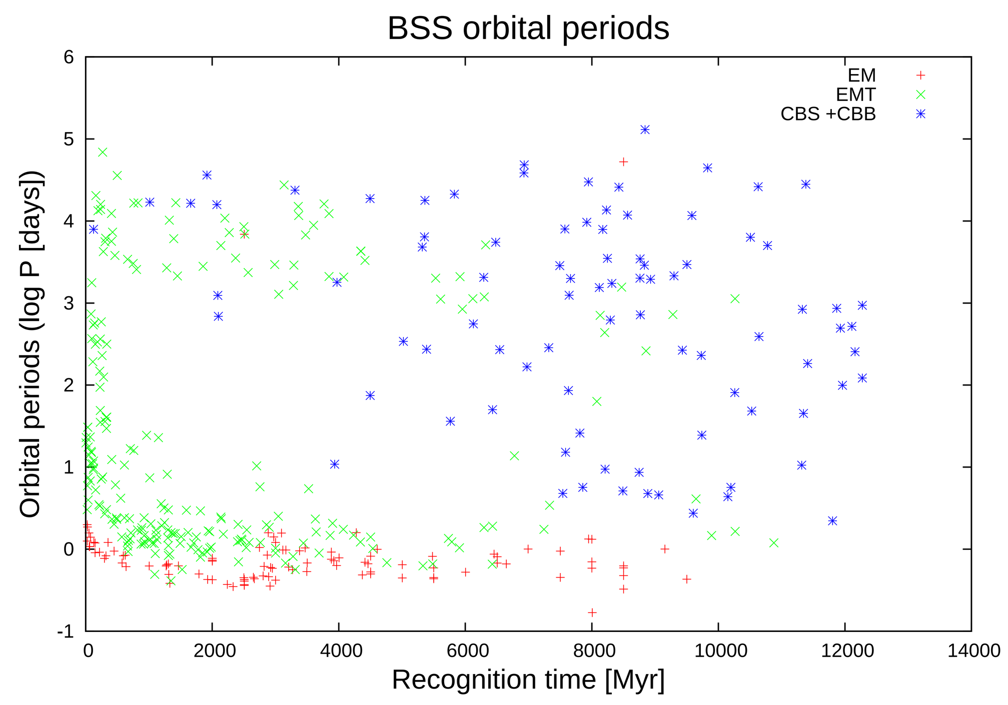


- distinct creation scenarios of EMT: short (Roche lobe overflow), medium and long period (stellar winds and envelope ejection)
- mass ratios for long period EMT fit to $q = M_{turn-off}/M_{WD}$ because:
  - the nominator: masses of long period EMT are just slightly larger than $M_{turn-off}$ (typically 0.1 $M_{\odot}$ after 500 Myrs)
  - the denominator: WDs are companions in the long period EMT (masses of WDs calculated based on Chernoff & Weinberg (1990, Tab. 1))
- mass ratios of long period EMT have a narrow range and predictable values through the entire simulation
- majority of long period EMT are short living BSS and dormant BSS (star gains mass and waits to actually exceed the $M_{turn-off}$)

EVOLOLUTIONARY MERGER (EM)

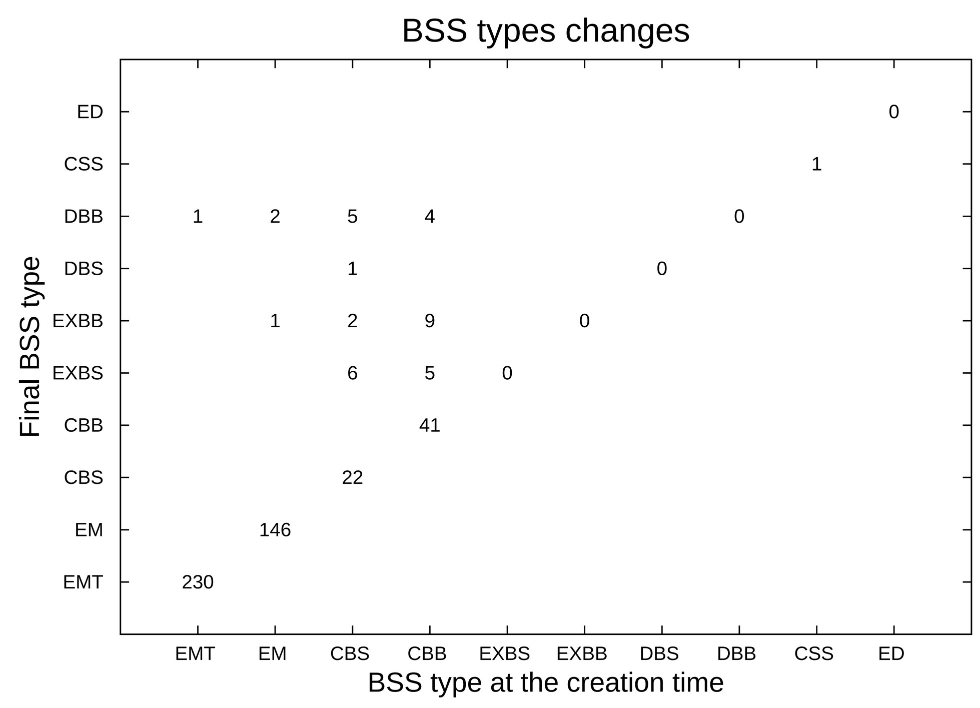
- EM BSS are compact objects, with orbital periods $\sim$ 1 day or less and circular, or almost circular, orbits
- two distinct formation scenarios:
  - merger due to the Roche lobe overflow mainly for EM $\leq$ 3 Gyrs
  - merger due to magnetic braking mainly for EM $\geq$ 3 Gyrs – at the time $T \sim 3$ Gyrs the $M_{turn-off}$ equals 1.25$M_{\odot}$ and the magnetic braking starts to work for both components in binaries with MS stars (see Fig. in the next panel)
- the majority of EM BSS have masses which are just slightly above the $M_{turn-off}$ – almost all of such EM are the dormant EM, and when dormant EM are detected, they have masses just slightly larger than the $M_{turn-off}$

COLLISIONAL BSS (CSS, CBS, CBB)



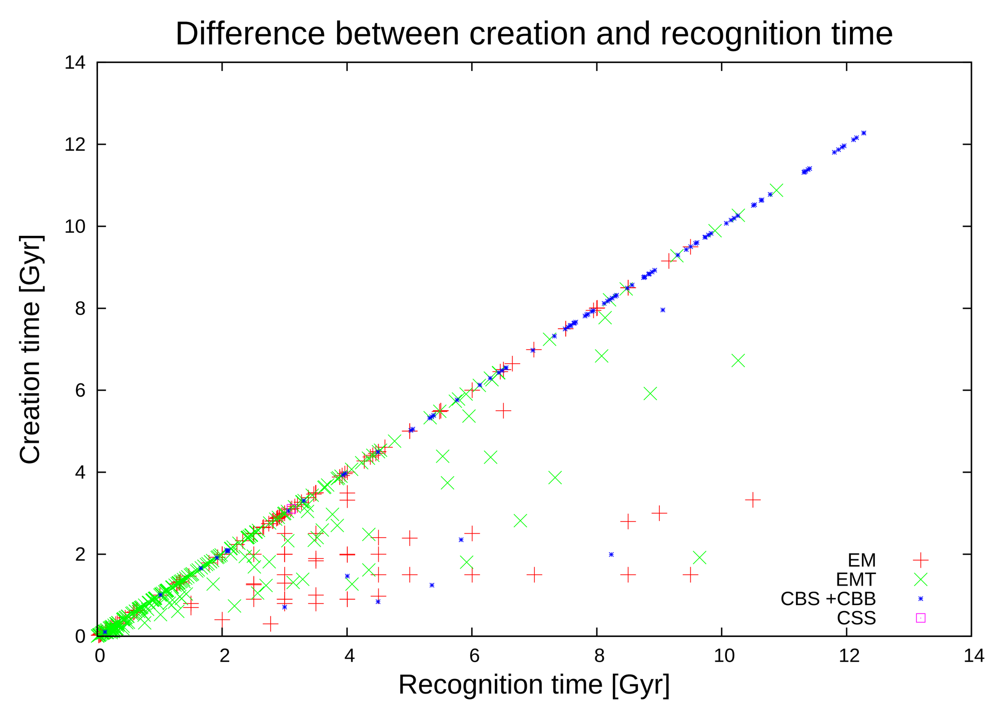
- after core starts to collape ($\sim$ 6 Gyrs) there are more CBS and CBB, they are created also from more compact binaries
- masses of CBS and CBB are roughly uniformly distributed from 1 up to 2 $\times M_{turn-off}$
- there is only one CSS in the whole simulation – maybe for different intial conditions there will be more CSS e.g. for star clusters with higher concentrations?

BSS TYPES CHANGES



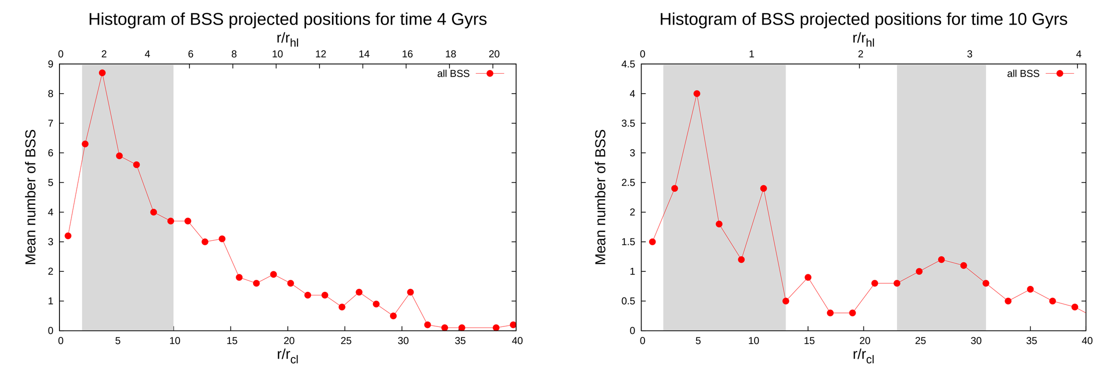
- BSS type changes for channels EM and EMT are not significant
- BSS initially created as CBS and CBB change their types to EXBS, EXBB, DBS, DBB
- dynamical interactions (exchanges and dissolutions) starts to play a significant role for CBS and CBB during and after core collaps at $\sim$ 8 Gyrs

BSS WITH DELAYED DETECTION



- for many BSS there is significant delay before the actual detection
- last merger or the last mass transfer can happen even several Gyrs before BSS actually exceeds the $M_{turn-off}$
- this effect was not expected in common scenarios for creation BSS; it was rather assumed, that mergers between stars create BSS immediately
- there were 30% dormant EM, 26% dormant EMT and 7% dormant CSS, CBS, CBB – for the total 476 BSS there were overall 112 dormant BSS which is 24%

BIMODALITY

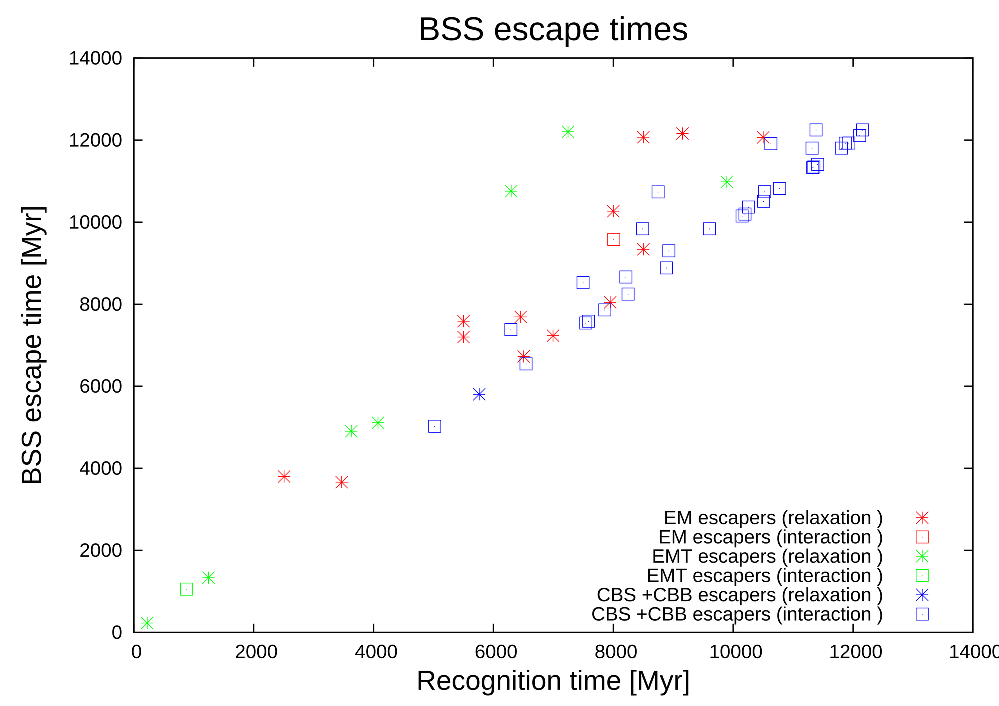


- bimodality at 4 Gyrs is not present yet but signs of bimodality becomes visible after the core collapse at 10 Gyrs
- perhaps bimodality is present after the core collapse? It would be a great tool to probe dynamical stage of star clusters

POSSIBLE INDUCED EM AND EMT

- we checked whether dynamical interactions can influence the population of BSS
- we performed simulation with and without *Fewbody* and with simple population synthesis – the numbers of EM and EMT are essentially the same for all three cases
  - it favors the conclusion that the dynamical interactions do not have significant influence on the creation of EM or EMT
- in the next paper (Giersz et al., 2011) for a simulation with higher impact parameters, there are significantly more BSS
  - this, in turn, suggests that the dynamical interactions could have some influence on the creation of BSS
- we will try to determine whether the dynamical interactions have indeed some implications for the population of EM or EMT in our future work

ESCAPERS



- CBS and CBB escape due to dynamical interactions and are fast escapers (the time between the creation and the escape time is small)
- EM and EMT escape due to the relaxation processes (slow escapers)
- number of BSS escapers (especially CBS+CBB) increases during and after the core collaps (> 8 Gyrs)
- 43% of CBS and CBB escaped as BSS, but after the core collaps, it is 60% – one can try to search for them in tidal tails of post-collapse stars clusters (especially slow escapers)

CONCLUSIONS

We described here an improved code for simulations of star clusters, called MOCCA. It is currently the only code which allows to study full scale evolution of large real star clusters and detail comparison with observations. MOCCA code is much faster than N-body codes. For the same amount of time one can run multiple simulations to cover very wide range of initial cluster parameters. Instead of having one simulation from N-body, one can have hundreds of simulations from the MOCCA code and one can perform detail statistical analysis of the results. Additionally, MOCCA simulations give practically the same amount of information about the evolution of the star clusters as N-body codes, which makes it even more attractive.

For details see 2012arXiv1207.6700H.

REFERENCES

References

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Giersz M., Heggie D. C., Hurley J., Hypki A., 2011, ArXiv e-prints