The Effect on Cluster Evolution of Stellar Evolution Model Choice Using AMUSE

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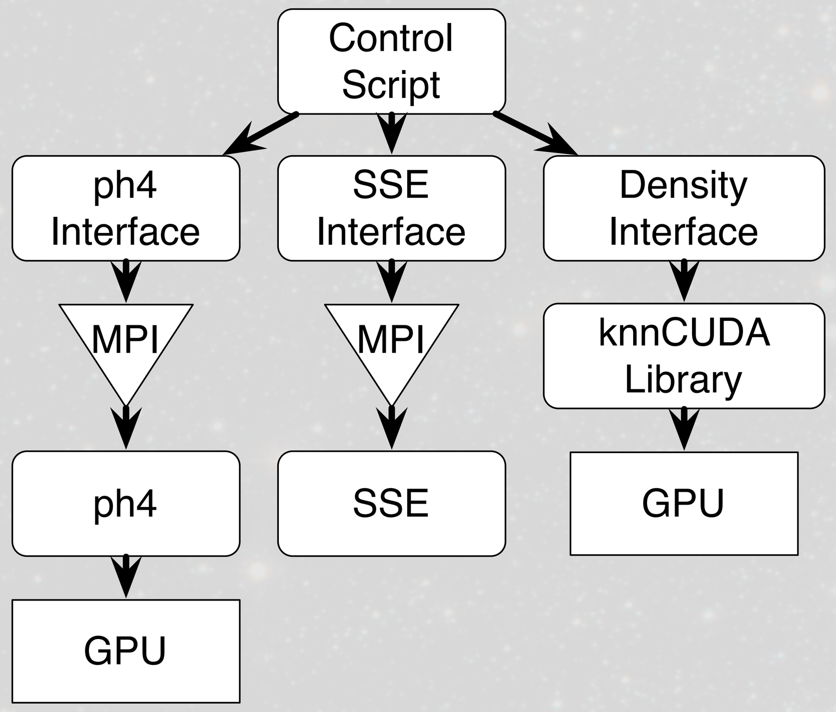
Introduction

Star clusters are typically modelled by computer simulation using N-Body gravitational dynamics and stellar evolution "recipes", which are derived from detailed stellar models. These recipes range from simple curve fits to data tables, through interpolation between precisely solved stellar structure models, all the way to fully-fledged "live" stellar physics simulations. A set of initial conditions is created using one of a common set of theoretical models, such as the Plummer or King models. These models typically describe a star cluster using continuum properties, such as density. A set of stars is generated which closely follows this distribution using a random number generator. In this work we examine the impact of the choice of stellar evolution recipe on the lifetime and evolution of a cluster. Additionally, we investigate the noise introduced into the simulation by using a randomly generated discrete realization of a continuous initial condition model. These simulations are conducted using a new community-based simulation framework called AMUSE (the Astrophysical Multipurpose Software Environment).

AMUSE

The Astrophysical Multipurpose Science Environment (AMUSE) is a new code base growing out of the MUSE project [7]. The core idea behind AMUSE is that it links together codes specialized to a single physical problem in order to create a multi-physics simulation rather than combining all codes into a single monolithic program.

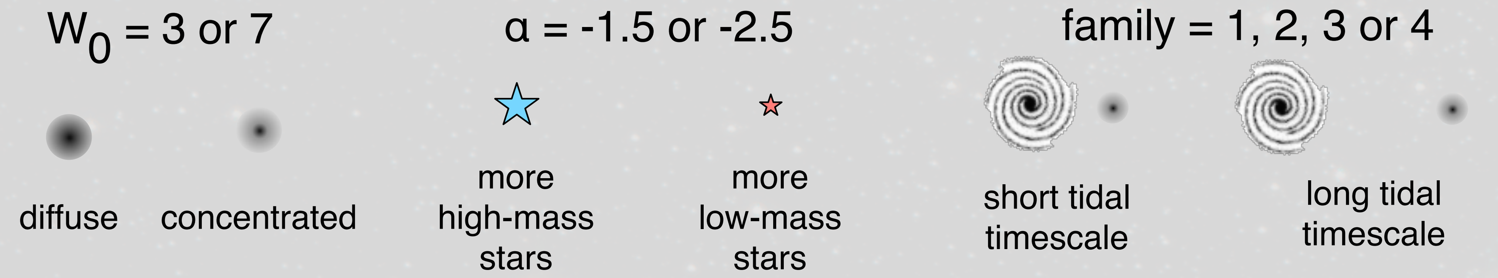


AMUSE uses MPI to allow each module to exist in its own process, possibly in parallel and on a different machine than the Python control script. The AMUSE framework provides an easy way to import new legacy codes.

ph4 [4] provides N-Body dynamics using SAPPORO [2] for GPU acceleration. SSE [5] provides stellar evolution. knnCUDA [3] is used to compute densities (12th nearest neighbour) in a stand-alone code similar to [1], but separate from AMUSE. This code finds all nearest neighbours, regardless of distance.

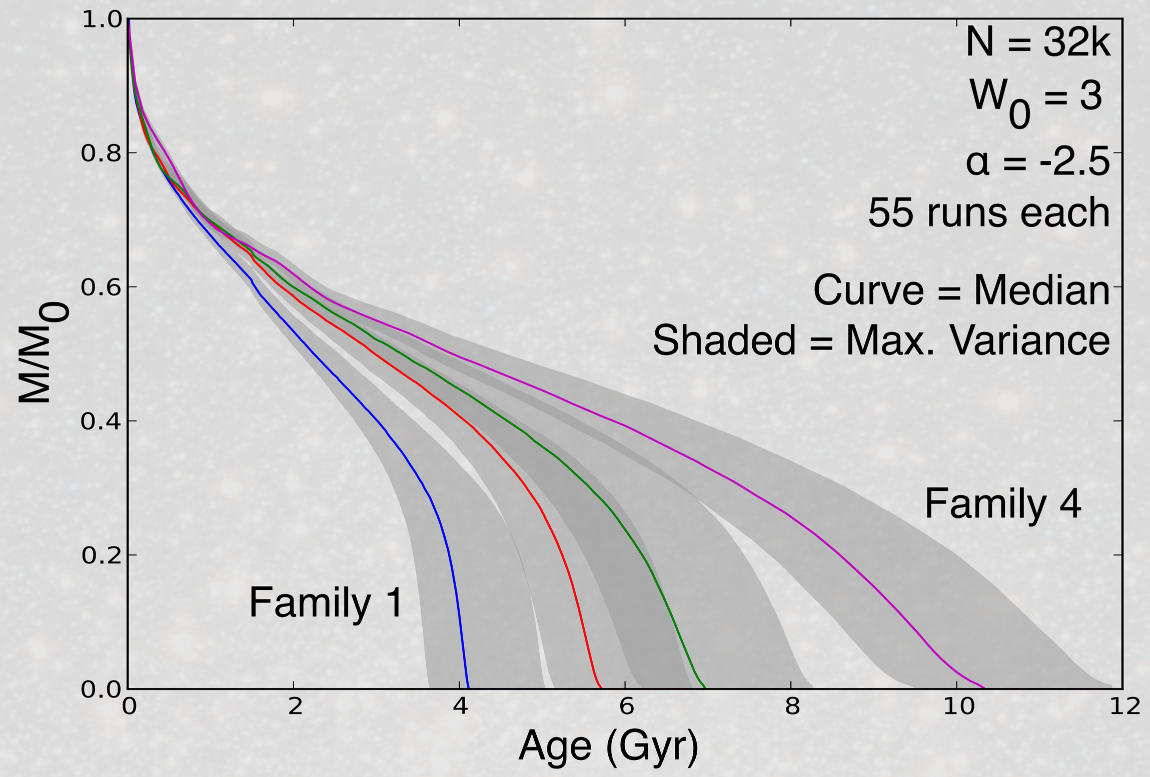
Models

King Models [6] of a star cluster are used. The degree of concentration is parameterized by W_0, while the slope of the initial mass function is denoted by α, with the Salpeter mass function corresponding to α=-2.35. The Chernoff & Weinberg [CW] family parameter determines the ratio of the dynamical and tidal time scales, equivalent to adjusting the galactocentric radius.



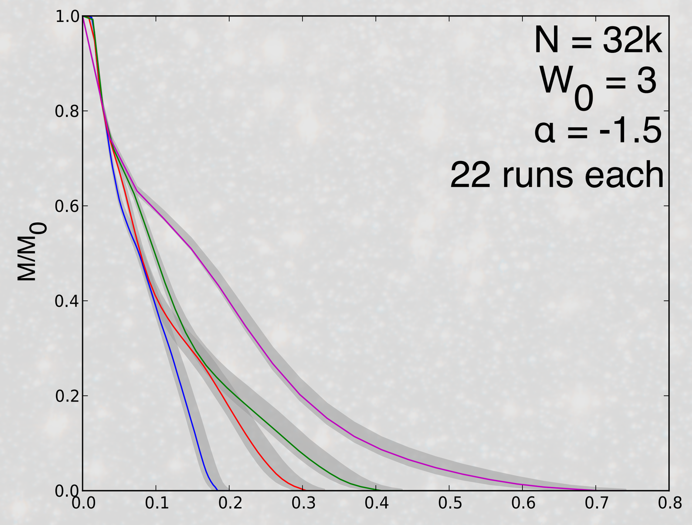
Tides are simulated using truncation at the Jacobi radius (= the King tidal radius). For all displayed runs, N = 32,000. Runs with N = 1,000 and N = 8,000 were also conducted.

Variation in Initial Condition Generation

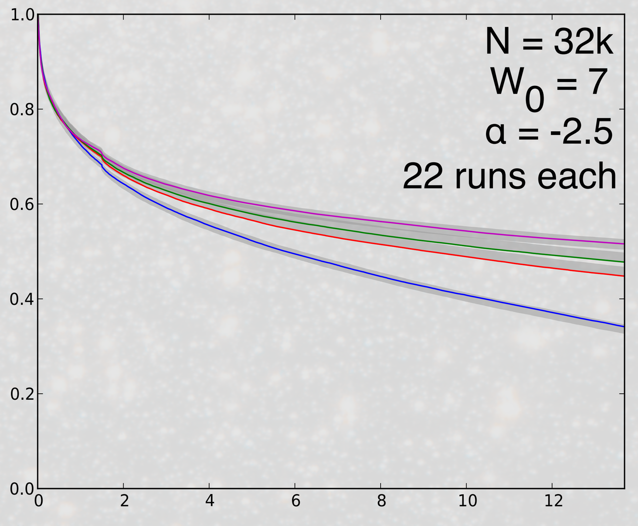


Variation in the initial condition generation significantly impacts lifetime and evolution...

This plot shows rapidly (relative to relaxation time) dissolution of similar star clusters placed at different galactocentric radii. There is considerable variation in the lifetime of clusters with the same statistical properties due to the realization of the model.



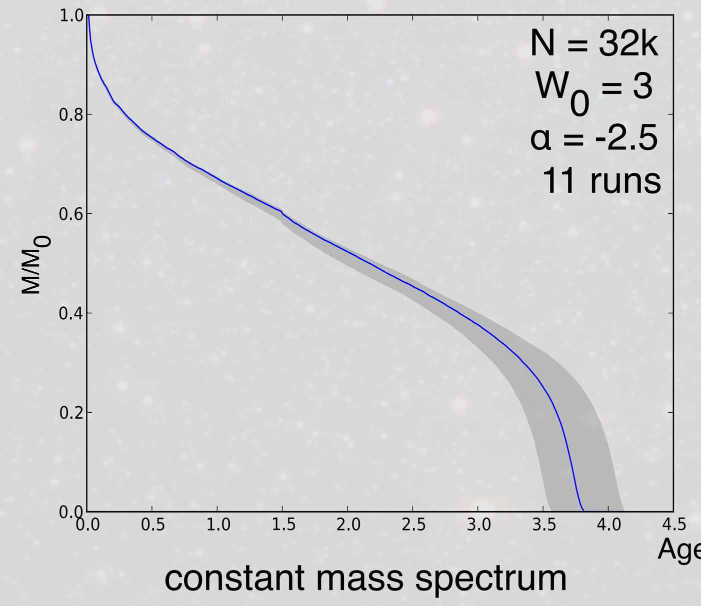
Stellar Evolution disrupts too quickly



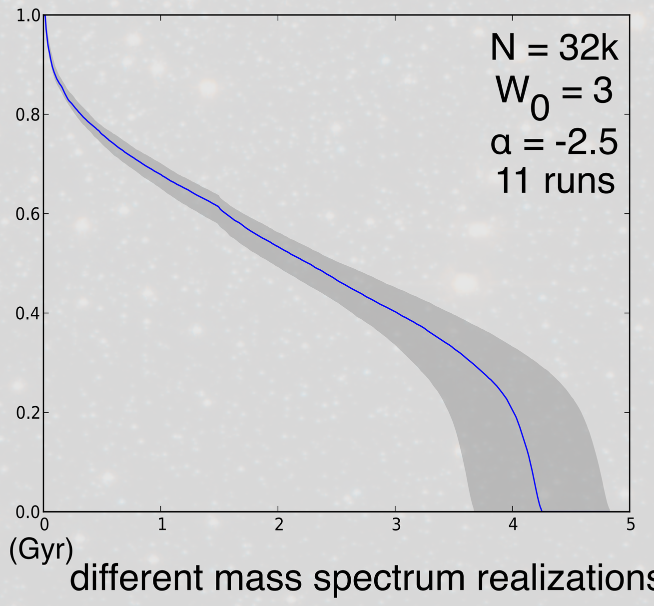
Tidal Field disrupts too slowly

... but only if the cluster dissolves at the right speed

The clusters at left are weakly bound and disrupted by the death of massive stars before the variation in initial conditions can have an effect. The clusters at right are tightly bound, which prevents the tidal field from "amplifying" the variation in the initial conditions.



constant mass spectrum
different spatial distribution realizations

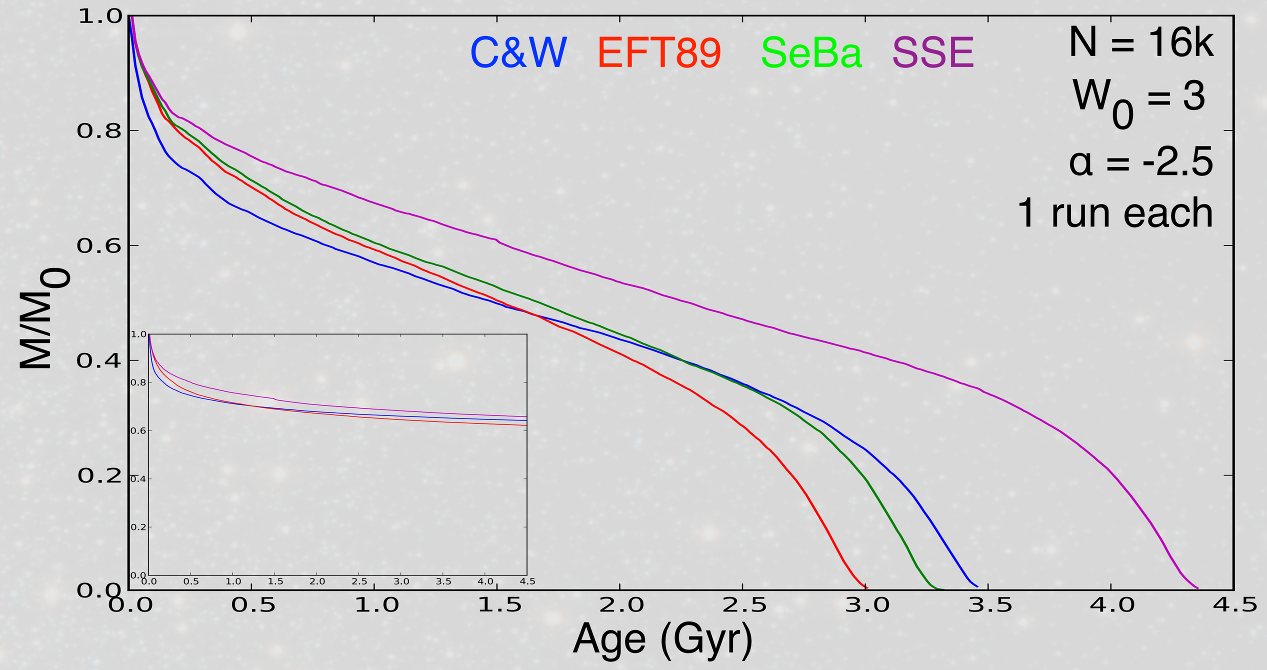


different mass spectrum realizations
constant spatial distribution

The clusters at left have the same stars in different spatial configurations. This introduces less variation than those at right, where the different random realizations contain different high mass stars in the same spatial configuration.

mass spectrum variation is most important, but variations in spatial distribution still matter

Stellar Evolution Model Comparison



This plot shows the same N=16,000 model evolved using different stellar evolution models [CW, 8, 9, and 5, respectively]. AMUSE easily allows switching stellar evolution models in the same code. All curves used AMUSE, except for the SeBa comparison which was computed with Starlab. The inset shows the population synthesis results for these models. Note that the variation between the different "recipes" is up to 25% of the lifetime, and is of the same order as the variation introduced by realization of the continuous model.

Conclusions

- The random variation introduced by translating a continuous initial condition model to a discrete one is significant, but only in clusters that dissolve quickly relative to the relaxation timescale and slowly relative to the stellar evolution timescale.
- The modular structure of AMUSE facilitates comparison of physics modules and enables exploration of assumptions and approximations that is difficult or impossible with other simulation codes.
- Specifically, AMUSE allows direct comparison of the effect of differing stellar evolution models. The choice of model can change the computed lifetime of a cluster near disruption by up to ~25%.

References

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Acknowledgements

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Further Information

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