Early dynamics and violent relaxation of multi-mass rotating star clusters

Alex Livernois[1], Enrico Vesperini[1], Maria Tiongco[2], Anna Lisa Varri[3,4], Emanuele Dalessandro[5]

Abstract

We present the results of a study aimed at exploring, by means of N-body simulations, the evolution of rotating multi-mass star clusters during the violent relaxation phase, in the presence of a weak external tidal field. We study the implications of the initial rotation and the presence of a mass spectrum for the violent relaxation dynamics and the final properties of the equilibria emerging at the end of this stage.

Structural Evolution

- The simulations have two different types of spatial initial distributions, clumpy and homogeneous. The clumpy systems are set with a fractal distribution, using a fractal dimension of 2.6.
- The systems are initially cold, which causes clumps to form and merge as the system collapses.
- In the post-maximum-contraction phase, the more tangentially-biased velocity distribution of systems with initial rotation can delay the merging of the stellar clumps that survive the maximum contraction phase and extend the time required for a system to reach a final monolithic structure.

Anisotropic Mass Segregation

Massive stars preferentially align their orbits with respect to the initial rotation of the cluster (Fig. 1)

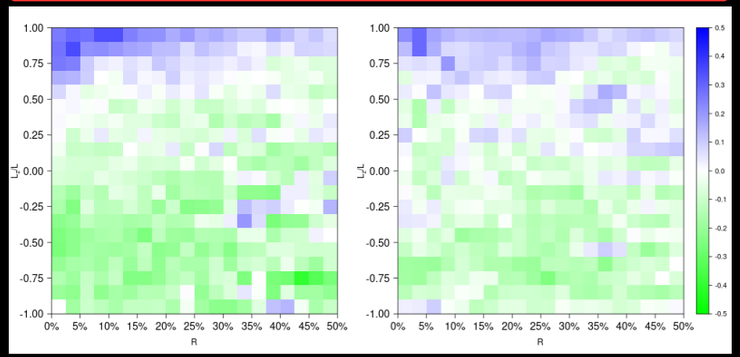

Figure 1: Enhancement of average mass of different Lagrangian cylindrical radii and orbital alignment (measured by the ratio of the z-component of the angular momentum to the total angular momentum) bins for an initially homogenous (left) and initially clumpy (right) cluster.

Mass Segregation and Evolution towards Energy Equipartition

Mass segregation (Fig. 2) and evolution towards energy equipartition (Fig. 3) develop on local scales during the very early stages of the cluster's violent relaxation phase within the stellar subsystems and are conserved through the hierarchical merging process.

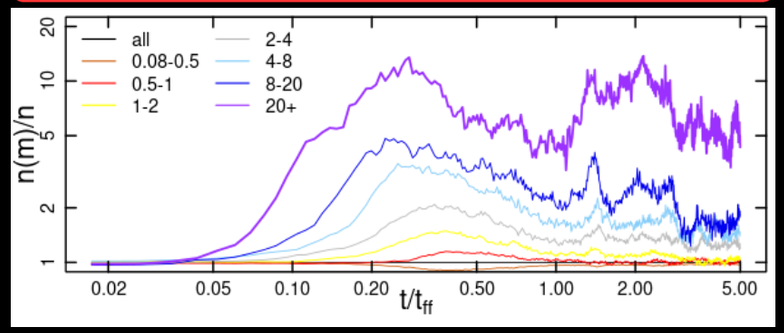

Figure 2: Time evolution of local mass segregation measured by the ratio of the local number density of each mass group to that of the entire cluster (this plot refers to a simulation starting with a fractal spatial distribution, see Livernois et al. 2021 for further details).

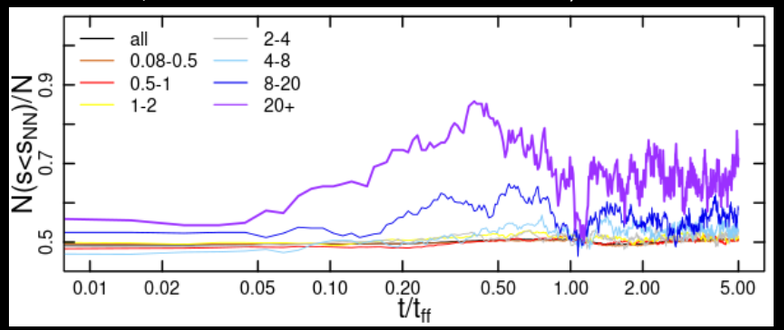

Figure 3: Time evolution of fraction of stars slower than the median speed of their 20 nearest neighbours. This plot shows that this fraction evolves to larger values for massive stars and illustrates the development of mass dependent kinematics (this plot refers to a simulation starting with a fractal spatial distribution, see Livernois et al. 2021 for further details).

Further Information

Further information can be found in Livernois et al. 2021: Early dynamics and violent relaxation of multimass rotating star clusters - NASA/ADS (harvard.edu)

Mass-Dependent Rotation

- At the end of the violent relaxation phase, rotating systems are characterized by mass-dependent rotation curves (Fig. 4), where massive stars rotate around the cluster center more rapidly than low-mass stars
- We interpret this trend as the outcome of the combined effect of angular momentum conservation, spatial segregation, and anisotropic segregation of massive stars.
- This effect is weaker in initially clumpy clusters (right) in which the less ordered nature of the violent relaxation collapse and re-expansion phases leads to a more effective kinematic randomization.

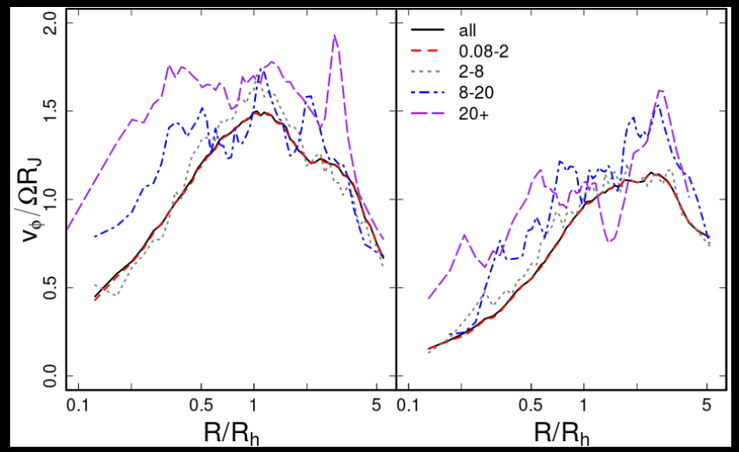

Figure 4: Radial profile of the rotation velocity for each mass range (given in solar masses in the legend) for an initially homogenous (left) and initially clumpy (right) rotating cluster once they have reached equilibrium.

Affiliations

1 Department of Astronomy, Indiana University, Bloomington
2 University of Colorado, JILA and Department of Astrophysical and Planetary Sciences
3 Institute for Astronomy, University of Edinburgh, Royal Observatory
4 School of Mathematics and Maxwell Institute for Mathematical Sciences, University of Edinburgh
5 INAF—Astrophysics and Space Science Observatory