Leiden-BNU Astronomy Summer School
Computational Astrophysics projects

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Please refer to the Github repository[1] for template scripts for the projects. You can also find additional examples in the AMUSE repository[2].

Project 2: Dynamical evolution of star clusters

Introduction

Most stars are not born in isolation. They are formed in clustered environments, gravitationally tied to other stars [Lada and Lada, 2003]. In time, clusters evolve and eventually dissolve, populating the field stars. The dynamical evolution of star clusters depends on both internal and external factors. Internal factors are, for example, two body relaxation and stellar evolution. External factors can be the interaction with the tidal field of the galaxy or with giant molecular clouds. In this project we will study how clusters with different initial conditions go through distinct evolutionary paths, and how the gravity of other stars in the galaxy affects the evolution of the cluster.

1 Initial conditions

Create different star clusters using some combinations of the following initial conditions:

1. **Number of stars**: 10, 100, 1.000, 10.000
2. **Stellar distributions:** Plummer sphere, King sphere, fractal
3. **Fractal dimensions:** 1.2, 1.6, 3.0
4. **Virial radius:** 0.1 pc, 0.5 pc, 1.0 pc
5. **Virial ratio:** 0.1, 0.5, 0.7

Use a Kroupa initial mass distribution with upper limit 100 $M_\odot$ [Kroupa, 2001].

2 Evolving isolated clusters

Evolve the star clusters for 100 Myr, or longer if the code is not too slow. To understand the underlying dynamics, look to answer the following questions:

1. How many stars remain bound to the cluster in time? How does the mass change inside a determined radius?
2. How does the half-mass radius of the cluster change in time? (The half-mass radius of a cluster is the radius containing half of the total stellar mass)
3. How does the spatial distribution of the cluster change in time?

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[1] https://github.com/franciscaconcha/LeidenBNU2019
[2] https://github.com/amusecode/amuse/tree/master/examples

4. How long does it take for an isolated cluster to dissolve completely?

You can make plots of different cluster properties to find answers to these questions.

3 Evolving clusters in a galactic potential

A star cluster will normally not evolve in isolation, but it will be subject to the potential of its host galaxy. We can define a simple galactic potential and use AMUSE's `Bridge` package to evolve the cluster under its effect.

1. Create a galactic potential.
2. Choose one of your isolated star cluster initial conditions and use them to create a new cluster.
3. Use `Bridge` to couple the cluster dynamics code to the galactic potential.
4. Evolve the system for 100 Myr, or longer if possible.

How does the cluster evolution change, compared to the isolated case? How long does it take for the cluster in the galaxy potential to dissolve?

Try different initial conditions for the star clusters. How does the final distribution of the stars change?

Make a plot of the stellar distribution at the end of the simulation.

4 Visualizing the results

Make movies of the dynamical evolution of clusters with two different initial conditions, for the isolated and galactic potential case. Use different colors for stars of different masses. What happens to the stars with masses higher than $1 M_\odot$? And to the lower mass stars?

5 Useful scripts

The following scripts from the AMUSE examples will be useful for this project:

- `/examples/textbook/gravity_minimal.py`
- `/examples/textbook/gravity_potential.py`
- `/examples/textbook/solar_cluster_in_galaxy_potential.py`

References

[Kroupa, 2001] Kroupa, P. (2001). On the variation of the initial mass function. *Monthly Notices of the Royal Astronomical Society*, 322(2):231–246.

[Lada and Lada, 2003] Lada, C. J. and Lada, E. A. (2003). Embedded clusters in molecular clouds. *Annual Review of Astronomy and Astrophysics*, 41(1):57–115.