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 4: Evolution of a triple stellar system

Introduction

The Trapezium cluster (M42, NGC1976) is one of the closest young star forming regions, comprising about 10^3 stars within a radius of ~ 3 pc. The age and the number of stars are uncertain, and even though the cluster has just emerged from its parent molecular cloud, the origin of its spatial and kinematic structure remains unclear. The close proximity of the Trapezium cluster allows detailed observations of circumstellar disk sizes using HST/WFPC2 [Vicente and Alves, 2005]. This size distribution is well described by a power law, but the origin of this distribution is not well understood. Vicente and Alves (2005) argue that "[Despite] the young age of the Trapezium, given that disk destruction is well underway, it is perhaps too late to tell if the present day disk size distribution is primordial or if it is a consequence of the massive star formation environment." We can write a small AMUSE script to test this hypothesis, and to study the evolution of the size distribution of circumstellar disks. We will reproduce the work done by [Portegies Zwart, 2016].

1 Initial conditions

- Create a distribution of 2500 stars, with a Kroupa initial mass function and a Plummer sphere spatial distribution.
- Give your cluster a virial radius of 0.5 pc and a virial ratio $Q = 0.5$ so that it is in virial equilibrium.
- To each star in the cluster assign a `disk_size` and `disk_mass` attribute. Initalize them as:

$$R_{disk} = 400 \text{ au}$$

$$M_{disk} = 0.1 \times M_*$$

- Write functions to change the disk radii and masses after an encounter. If a disk has a truncating encounter, its new radius is defined as:

$$R'_{disk} = 0.28d \left(\frac{M_1}{M_2}\right)^{0.32}$$

  where d is the encounter distance M_1 and M_2 are the masses of the stars in the encounter. The new mass of the disk is given by:

$$M'_{disk} = M_{disk} \frac{R_{disk}^{1/2} - {R'_{disk}}^{1/2}}{R_{disk}^{1/2}}$$

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

2 Evolve the system

Use an N-body integrator such as `ph4` to evolve your system. Make sure to write a stopping condition that is called when two disks have an encounter, and which handles the new disk sizes and masses. Evolve the system for 1 Myr. Plot the final disk sizes. Plot the disk sizes obtained by [Vicente and Alves, 2005] and compare your distributions. How do your disks compare to the observations?

3 Different initial conditions

Problems like these, where dynamics between stars are very important, depend strongly on initial conditions. Rerun the experiment trying different combinations of initial conditions, such as:

- Keep the same configuration as before, but with virial ratios $Q = 0.3$ (subvirial, velocity dispersion of stars is lower than in equilibrium) and $Q = 0.7$ (supervirial)
- Try different virial radii for the Plummer sphere, between 0.1 and 1.0 pc.
- Instead of a Plummer sphere, try fractal distributions with fractal dimensions 1.2, 1.6, and 2.0.

Evolve these systems for 1 Myr and plot the final disk sizes. Plot all your experiments together, along with the observations. Which model provides a better fit to the observed disk sizes?

Choose some of your experiment and make a movie of the locations of the stars in the cluster over time. Use different colors for different stellar masses. What happens to the stars as the cluster evolves? Where are the most stars concentrated? Where are the massive stars concentrated? How do you think this affects your results?

4 Useful scripts

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

- `/examples/textbook/gravity_kepler_disks.py`

References

[Portegies Zwart, 2016] Portegies Zwart, S. F. (2016). Stellar disc destruction by dynamical interactions in the Orion Trapezium star cluster. , 457(1):313–319.

[Vicente and Alves, 2005] Vicente, S. M. and Alves, J. (2005). Size distribution of circumstellar disks in the Trapezium cluster. , 441(1):195–205.