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 1: Stellar merger

Introduction

Stellar mergers can occur as a part of binary or multiple star system evolution, or as a product of dynamics in regions of high stellar density. They can occur in close binaries that evolve into a contact phase [de Mink et al., 2014], or in regions of high stellar density such as galactic centers and star clusters.

1 Initial conditions

1. Create two stars of masses 1 $M_{\odot}$ and 3 $M_{\odot}$.
2. Evolve both stars for 150 Myr using a stellar evolution code such as `MESA`, `SeBa`, or `EVtwin`.
3. Turn the stellar structure objects returned by the stellar evolution code into an SPH particle representation, using 1000 SPH particles. If your code is too slow you can try using less particles.
4. Set the initial positions and velocities for the particles of each star.

2 Relaxation of SPH codes

The conversion from a grid code (such as the result of a stellar evolution code) to SPH can leave the star slightly out of equilibrium. We address this problem by "relaxing" the SPH model. The relaxation process consists in slowly reducing the velocities while running the hydrodynamics code with short time steps. Do this for both stars.

3 Merger

1. Move both stars to the center of mass of the system.
2. Start an instance of the SPH code `Gadget2`.
3. Add the SPH particle sets of both stars to the SPH code.
4. Evolve the system in 1 yr time steps and save the diagnostics to a file.

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

4 Recognizing a star in the collision product

SPH collisions such as the one implemented in this project can result in objects that are hard to recognize due to asymmetries or rotation speeds. In AMUSE you can use the "hop" clump finder code to detect a star in your collision result.

1. Use "hop" to find clumps in your stellar merger.
2. Choose the larger clump as your new star.
3. Copy the right particle properties from the SPH particles to your "hop" selected particles.
4. Remove the particles that are not part of the new star.

5 Convert SPH back to stars

Now you can convert your SPH model back to a stellar structure. This process is not straightforward, because the stellar evolution code expects a structure in thermal equilibrium, which might not be the case. The function can take a long time to run.

Once you are back to a stellar structure, evolve the new star for a few more Myr.

6 Visualizing the results

Plot the evolutionary tracks in temperature vs. luminosity of the initial stars and of the merger product. How do these compare? How does the evolution of the merger product deviate from the evolution of a star that initially had the same mass? Does the merger product look younger or older than a star with the same mass at the same time?

Make plots at different time steps of the stellar merger process. How much mass is lost when you find the resulting star?

7 Extras

Only do the next steps if you have enough time!

1. **Convergence test.** When using SPH it is very important to perform convergence tests to decide how many particles to use. In this way we make sure that the results are due to the actual physics of the process, and not due to random deviations in the particles. Repeat the experiment using 100, 200, 400... SPH particles for each star. Plot how a specific parameter of your code changes: this can be the energy of the particles, the mass of the merger product, etc. At which number of SPH particles do your results converge?
2. **Different masses.** Repeat the experiment using different mass combinations for the encountering stars. How do your results change?

8 Useful scripts

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

- `/examples/textbook/merge_two_stars_sph.py`
- `/examples/textbook/merge_two_stars_sph_evolve.py`

References

[de Mink et al., 2014] de Mink, S. E., Sana, H., Langer, N., Izzard, R. G., and Schneider, F. R. N. (2014). The Incidence of Stellar Mergers and Mass Gainers among Massive Stars. , 782:7.