Leiden-BNU Astronomy Summer School
Computational Astrophysics projects

Francisca Concha-Ramírez*
TA: Martijn Wilhelm†

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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: Neutron star hits companion

Introduction

Neutron stars are the smallest and densest stars. They are the remnant of the supernova explosion of a massive star. Once a neutron star forms they are no longer actively generating heat, which causes them to cool over time. However, they can still accrete material and interact with a binary companion. The first detection of a collision between two neutron stars was observed as gravitational waves by LIGO-Virgo in 2017 [LIGO Scientific Collaboration and Virgo Collaboration, 2017].

Because of their formation through a supernova explosion, neutron stars can receive huge velocity kicks when they are formed. Theoretically, this could lead to the collision of the neutron star with it binary companion. In this project we will study the collision of a neutron star with a secondary, main sequence star.

1 Initial conditions

- Create a star of $10M_\odot$
- Transform the star into an SPH realization. Use the SPH codes `Fi` or `Gadget2`. Initially, use 100 SPH particles.
- Create a neutron star of $1M_\odot$ as a single dark matter particle (`dm_particle`) in the SPH code.
- Locate the neutron star at a distance $d = R_*$ where R_* is the radius of the main sequence star. The centers of both stars should be aligned in the x axis (impact parameter $b = 0$)
- Give the neutron star a kick velocity of around 1000 km/s directly onto its companion.

2 Convergence test

When working with SPH codes it is important to check that the number of particles used is enough so that the results we obtain are due to physical effects, and not to random noise. A way to check this is by performing convergence tests: running the same experiment many times for different numbers of particles. Once the results converge, you are in the range of particle number that is safe to use.

- Evolve the model set up with the initial conditions above, and answer the following questions:
  - Does the neutron star stick to its companion, or pass through it?

* fconcha@strw.leidenuniv.nl
† wilhelm@strw.leidenuniv.nl
[1] https://github.com/franciscaconcha/LeidenBNU2019
[2] https://github.com/amusecode/amuse/tree/master/examples

- How much mass does the main sequence star loose in the impact?
- What is the kinetic energy of the ejected mass?

- Repeat the simulation a few times, increasing the number of SPH particles for the main sequence star. Try up to 1000 particles, in steps of 100. At what point do the mass loss and kinetic energy converge?

3 Dependence on impact velocity

Once you have decided on a number of SPH particles to use, set the impact parameter b (the initial position of the neutron star in the y axis) to $b = R_*$. Using this initial configuration, repeat different simulations decreasing the initial velocity of the neutron star. At what velocity does the neutron star stay bound to its companion?

4 Dependence on impact parameter

Repeat the same experiment as before, but using different impact parameters between $b = 0$ and $b = R_*$. At what point does the neutron star become bound to its companion? Plot of the kick velocity for which the neutron star just becomes bound as a function of the impact parameter.

What velocity is needed to shoot the neutron star right through the center of the companion?

References

[LIGO Scientific Collaboration and Virgo Collaboration, 2017] LIGO Scientific Collaboration and Virgo Collaboration (2017). Gw170817: Observation of gravitational waves from a binary neutron star inspiral. *Phys. Rev. Lett.*, 119:161101.