Assignment 4:

0.1 Neutron star hits companion

Neutron stars receive huge velocity kicks upon formation. Sometimes this might lead to the collision of the neutron star with the companion, which might produce an interesting observational phenomenon. Such event, by the way, has never been observed yet.

Construct a hydrodynamics realization of a main-sequence star of $10\,\mathrm{M}_{\odot}$. Fire a neutron star at the star from a distance equal to twice the stellar radius ($R_{\star}$), with a velocity of $v_{\rm kick}$. You can chose $v_{\rm kick}$ pretty large, but during a supernova the newly formed neutron star can acquire such high velocities due to asymmetries in the explosion. This problem can be run with a grid or with an SPH code, although the latter makes it easier to include the neutron star as a point mass in the form of a `dm_particle`.

Set up an experiment to perform the simulation and measure the final parameters of the system. We wonder under what circumstances the neutron star sticks in the companion, possibly leading to a Thorne-Zytkov object [1], or the neutron star is captured by the companion in a binary system. The two free parameters in this problem are the velocity and direction of the neutron star's kick. Best is to stay in the binary plane, which reduces the problem to two parameters.

1. Perform a convergence test on the number of SPH particles for this problem where the neutron star is launched head-on into the star with a velocity of 1000 km/s (see § **??**).

   Run a first test with a few SPH particles in the target star, for example 100, and measure the behavior of the system. Does the neutron star stick to the companion star? What is the amount of mass lost by the target star, and what is the kinetic energy with which the ejected mass is lost? Run subsequent simulations with a higher resolution, 200 SPH particles, 400 particles, etc., until the results converge or until your patience runs out.

   Make a figure of the resulting diagnostics of the convergence test as a function of resolution.

   Repeat the simulation with different impact parameters, ranging from d = 0 (head-on) to d = $R_{\star}$. Measure the amount of mass lost from the main-sequence star, and indicate whether or not the two stars merge. Make a figure of the amount of mass loss as a function of impact parameter.

2. Perform the simulation with an impact parameter of d = $R_{\star}$ and reduce the velocity of the neutron star until the two stars remain bound. At what velocity does the neutron star becomes bound to its companion star.

3. Repeat these calculations and measure for each impact parameter ranging from d = $R_{\star}$ to d = 0 at what velocity the neutron star remains bound. Measure the orbital parameters at the moment it become bound. Make a plot of the kick velocity for which the neutron star just becomes bound as a function of the impact parameter.

4. What velocity is needed to shoot the neutron star right through the middle of it's companion. Can you understand the magnitude of this velocity?

5. In reality a neutron star is launched into the companion star from it's orbit. Can you comment on how likely it is that the neutron star hits it's comanion?

References

[1] K. S. Thorne, A. N. Żytkow, *ApJ* **212**, 832 (1977).