Fall 2013

ASTR 255: Astrophysics Research Methods

Problem Set #9 -- Due December 16, 2013

Numerical simulations are an extremely useful research tool. In this problem set, we will explore galaxy-galaxy interactions using the 3-body restricted and direct N-body simulation.

1. **Toomre & Toomre simulations**: These were the first computer simulations to investigate the behavior of galaxy-galaxy mergers. The Toomres solved the "3-body restricted" problem, rather than the full N-body problem, but captured many key features seen in galaxy merger systems and confirmed by more realistic codes. The paper can be found here:

   http://adsabs.harvard.edu/abs/1972ApJ...178..623T

   a. Explain in words the Toomre & Toomre algorithm. Describe the initial setup and what equations were solved to determine the position of particles in each time step. How is this different from a full N-body simulation?

   b. We have provide python code (Toomre.py) which sets up the Toomre problem. Run the code. Note that we are using the same tools as Problemset #1 to visualize the data.

   c. Modifying the code above to recreate Figures 1, 2 and 5 in the Toomre paper. To recreate these figures, you will need to modify the relative spin of the Galaxies, as well as their initial positions and/or velocities. You do not need to modify the initial ring of massless particles. Show snapshots from the simulations and state what parameters were need to replicate Figs 1+2+5.

   d. Chose a snapshot from one of your simulations above in which the galaxies appear disturbed. Find a image of a galaxy-galaxy merger which looks most like the simulation.

2. **Direct N-body simulations:** Direct N-body codes calculate the forces exerted on all N particles by all other particles in the simulation.

   a. Described in words how a direct N-body simulation works, beginning with the initial particle distribution, through calculating forces and advancing the particles. Write the out the equations for calculating force and advancing particles in velocity and position.

   b. **Bonus:** Modify the above Toomre python code so that it is a full N-body code. Calculate all forces (star-star and star-galaxy) in each timestep. You will need to chose the star particle masses and initial disk rotation velocity carefully. Chose one of the simulations above and compare the results for the mass-less and full N-body case.