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Galaxy Interactions via Runge-Kutte N-body Simulation

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ABSTRACT

In 1972, Toomre and Toomre showed that tidal tails and bridges develop even in some very simple 2 body simulation. This paper seeks to re-create some of the results seen in the Toomre and Toomre paper using the similar methods. The Runge-Kutte (RK4) method was used to numerically integrate the equations of motion for galaxies and particles associated with those galaxies that represent masses in the disk. This was done in 2D space.

1. INTRODUCTION

Tidal tails and bridges are structures that develop between interacting spiral galaxies that have begun to pass each other or have passed each other multiple times. These structure come from gas, dust, and stars being mutually ripped from each galaxy by the gravitational pull of the other.

Through the use of similar methods, RK4, I have attempted to reproduce similar observations in my simulation

2. METHODS

In order to create galaxies and particles, I used python objects. I created a galaxy object and a particle object. A galaxy object is made of particle objects. Some properties common between the two are x and y positions, x and y velocities, and location history for each coordinate. Galaxy objects then have lists of the particles associated with them and a mass property, where as particles do not have masses.

This simulation is essentially a three body problem given that the interactions between individual particles is not important over the time periods being considered in this simulation. This is because the period of time being simulated over is on the order of 1×10^7 to 1×10^8 years, which is less than the crossing time of stars in the galaxies. It is not really necessary to integrate approximations into the n-body simulation because it is just three body. The longest part is just iterating through all of the particles.

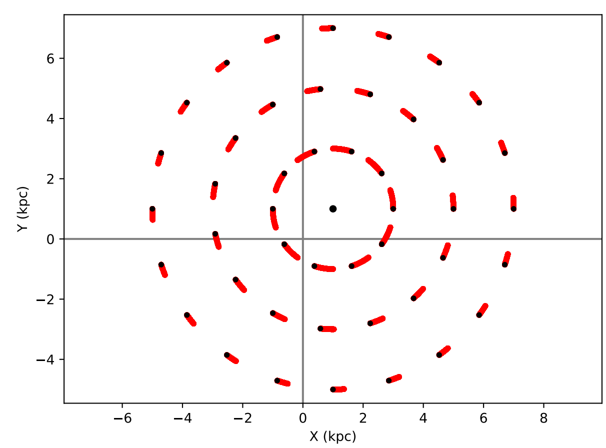

Figure 1. This plot shows circular orbits of particles, the axis hear are equally proportioned, so they appear circular as they should. The black point represents the starting point of the particles.

Particles are added to the galaxy via a galaxy method. These are added as specific radii, where the velocity of a particle is determined by its radius from the center and the mass of the galaxy. The method places a specified number of particles evenly spaced along the circle of radius R from the center. The particles are then added to a list that is part of the galaxy object so it can be called in later methods.

The simulation used 4th order Runge-Kutte to numerically integrate the equations of motion. It is used

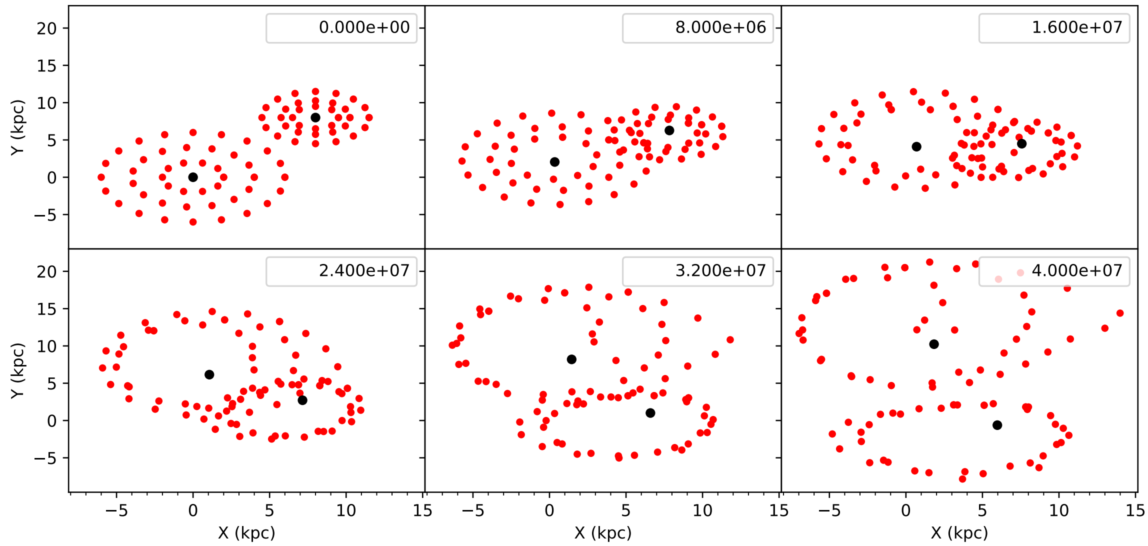

Figure 2. The first galaxy (bottom left) has an y-velocity of 300 km/s and a x-velocity of 50 km/s, while the second galaxy (top right) has a y-velocity of -250 km/s and an x-velocity of -20 km/s. The orbits of the particles do not appear circular because the axis are not equally proportioned.

to update both velocity and position. The basic idea behind calculating acceleration and updating both velocity and position are seen in Equations 1 - 3.

$$\sum \vec{a} = \sum \vec{F}/m = \sum -\frac{Gm}{|\vec{r}|^2}\hat{r} \tag{1}$$

$$v_{i+1} = v_i + a_i * h \tag{2}$$

$$r_{i+1} = r_i + v_i * h \tag{3}$$

3. RUNNING THE SIMULATION

The first thing I did to check that my method was working was to simulate simple particle orbits to check that they were nice and circular. This check is shown in Figure 1. There were some issues with the orbits if the time step was too big, but in general a time step of 100 to 200 years was sufficient to avoid these problems. A time step of 500 years could cause some issues with the orbits.

I created to example galaxies, one with particles at a radius of 2, 4, and 6 kpc and a mass of $1^{11} M_{\odot}$. The other galaxy had particles at radii of 1.5, 2.25, and 3.5 kpc and a mass of $1^{10} M_{\odot}$. The galaxies started at some distance from each other with velocities in opposite directions.

The results are seen in Figure 2. They are somewhat interesting and somewhat disappointing. There is not much formation of structure in the galaxies. One interesting thing is that the radii of star orbits expand outward radially like is seen in some of the Toomre and Toomre plots. But, in this work that expansion seems to be much larger. There is also some potential formation of tidal tail in the top galaxy of the bottom right plot of Figure2, but not to the degree that it is seen in Toomre and Toomre's simulations.

4. FUTURE WORK

Some obvious additions to this project would be to add a third dimension to test some more complicated configurations. This would also open up the possibility for more complicated galactic structures. It would also be nice to test more cases.