Galaxy Project

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PHYS-202

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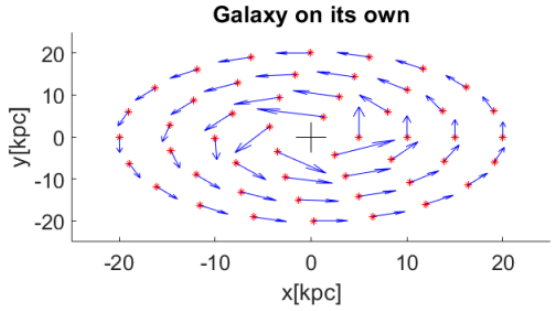
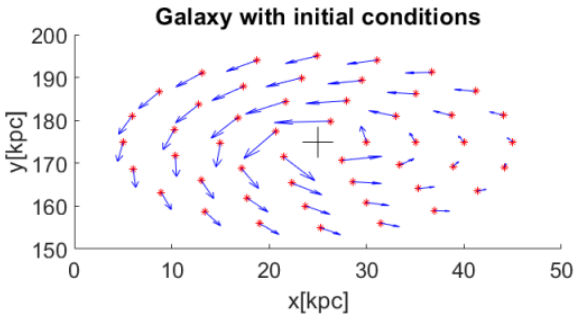
In recent years, scientists have sought to accurately model the interaction between galaxies. Dubbed "Galaxy mergers" and understood to be an important part in the evolution of galaxies, scientists turn to numerical methods to solve the differential equations involved. The Toomre brothers simulated mergers in FORTRAN and were able to demonstrate that "tidal tails" and "galactic bridges" came about due to the interaction between two galaxies. The Toomre & Toomre paper, while low in particle count, explained why we see tidal tails in *the Antennae* and *the Mice* galaxies[1]. The paper would pave the way for later discoveries, and with stronger computers at their disposal, scientists would be able to produce higher-resolution simulations of mergers. A 2008 paper by Bournaud, Duc, & Emsellem[2] utilized the supercomputer NEC-SX8R to model millions of particles per galaxy, and found that the interaction would even evolve into the formation of globular clusters - spherical satellite collections of stars that orbit the galaxy.. For our project, we followed a path similar to the Toomre Brothers.

In particular, our two galaxies were comprised of stars distributed evenly at 4 radii and given each a velocity so that they traveled tangential to the circle created.





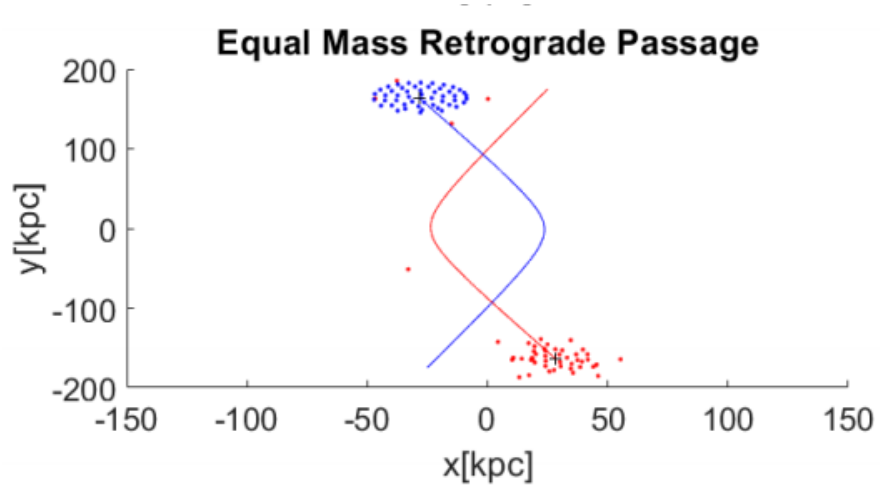
Using Matlab's ode45 function to solve Newton's Law of Gravitation, we then modeled how the two galaxies' gravities would pull each at each others' stars and alter each others' trajectories. Explicitly, the code was written to populate an array with different information

[1] http://www.spaceref.com/news/viewpr.html?pid=8197

[2] https://academic.oup.com/mnrasl/article/389/1/L8/996886

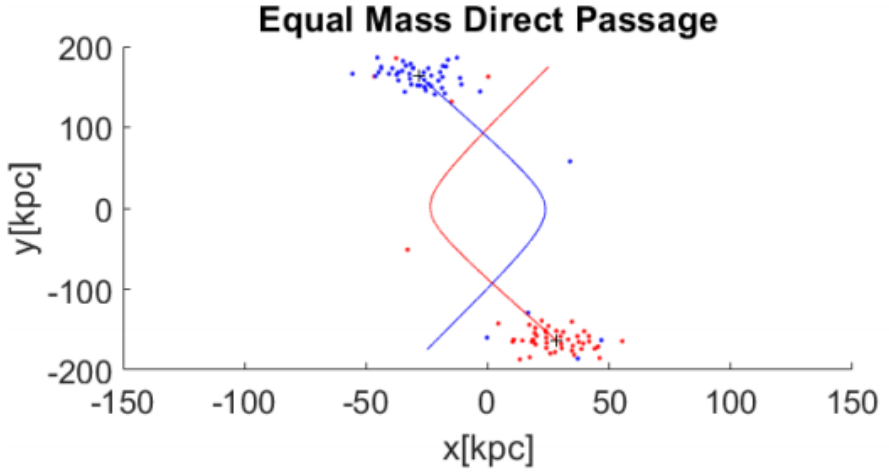
about the two galaxy system through time, where the data in the array would be selectively plotted. In the simulation, we studied different cases of one “intruder” galaxy traveling past a “parent” galaxy. The parameters varied were the direction that the intruder galaxy spun and its mass.

The first case was to test equal mass galaxies with the two directions of spin opposite to each other (Retrograde passage). In this case we found that the intruder galaxy would accrete stars from the parent, but also would be heavily altered and disfigured in comparison to the parent galaxy. The parent galaxies’ stolen stars would form a tail-like structure, thus demonstrating the formation of a “tidal tail”. Here we also observed the less-altered galaxy to have shrunk in radius.

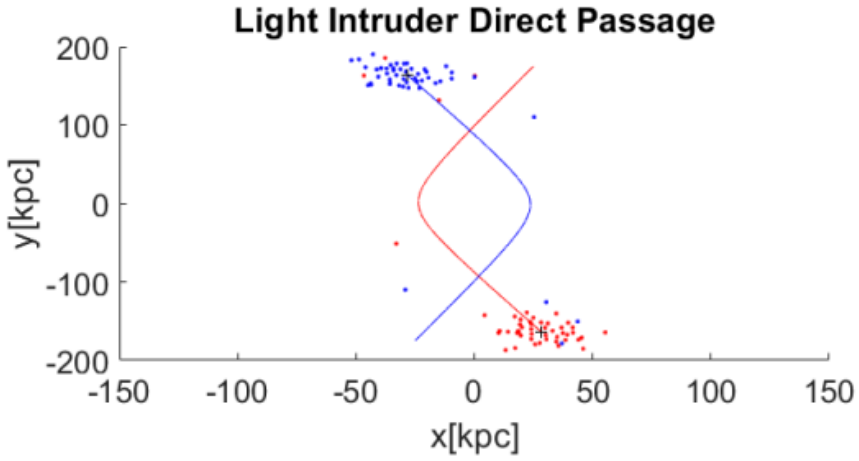


The second case was to test equal mass galaxies with the same direction of spin (direct passage). Setting the direction of the spin to be the same with equal mass would mean that the galaxies were identical except for starting position ensured that both galaxies were affected equal

and opposite, which was guaranteed by Newton's law of Gravitation (if implemented correctly).

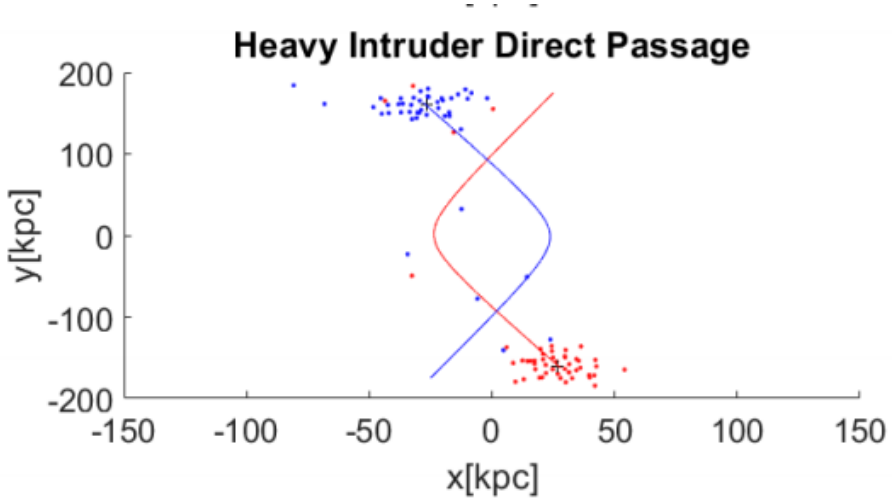


The third case involved a lighter intruder and direct passage. While not visible from the screenshot, the heavier parent galaxy's stars were stolen by the lighter intruder, and both galaxies were disrupted almost completely, with more emphasis on the lighter galaxy. This is physically reasonable, as we expected equal and opposite forces exerted by both galaxies, it would make sense that the lighter is offset more.



The fourth case was opposite the third in that it involved a heavier intruder and direct passage. While also not visible from the screenshot, the heavier intruder was able to steal more

stars from the lighter parent galaxy, and by the end, both galaxies were disrupted.



This project was a faithful recreation of part of the work done by the Toomre Brothers and served to demonstrate to the student how to apply numerical methods to solve scientific problems. More specifically, we proved that the interaction of two galaxies leads to the formation of tidal tails, and moreover reproduced the conclusion of the 1972 paper. Similarly, we must also note that the simulation does not have a high enough element count to completely accurately model the merger, but merely displays the key aspects of tails and bridges.