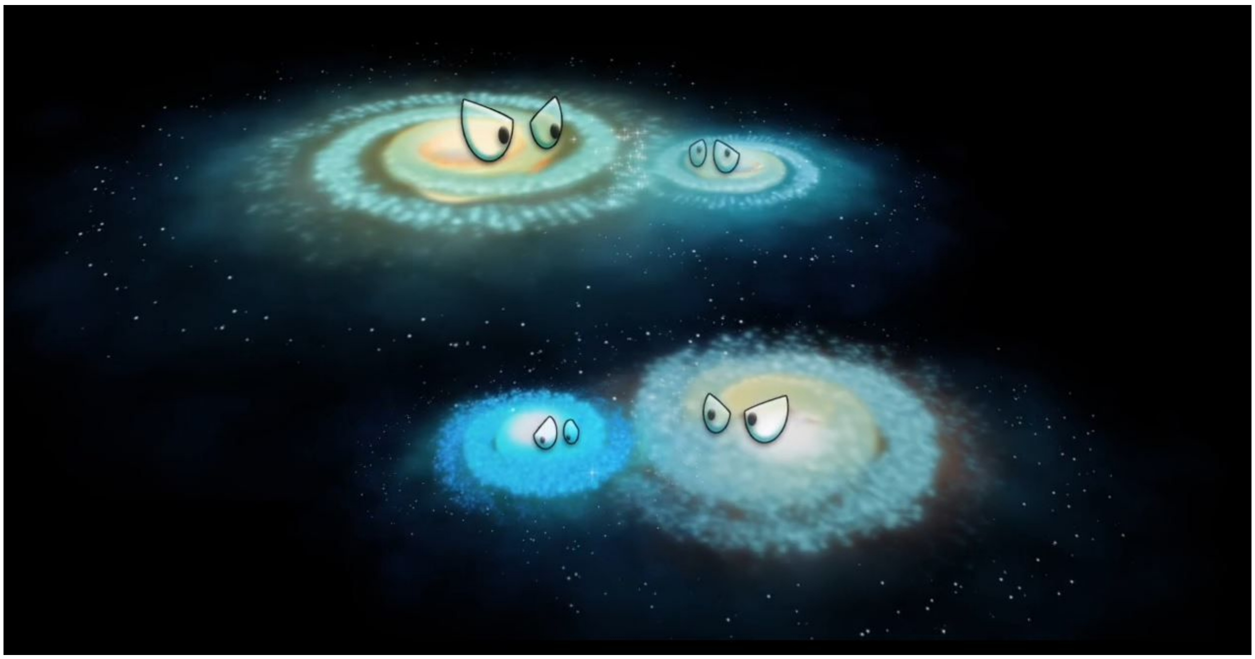
Project L : Simulation of Colliding Galaxies

Galaxy Collisions Simulation with Gadget 2



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INTRODUCTION

Originally after discovery, galaxies were seen as independent systems isolated from one another. In recent decades, it has become apparent that they interact often on large timescales; an individual galaxy will likely have one or two collisions over its lifespan and they are believed to have a significant impact on galaxy evolution. (1,2) However, this timescale is much larger than the lifespan of a human. Our observations of colliding galaxies is akin to taking a snapshot of the full interaction. Because of this, much of the research into galaxy evolution relies on N-body simulations.

These codes “evolve” particles forward in time by calculating the force on an individual particle, then using its velocity and acceleration to find its position at the next timestep. Parameters like the particle size, box size, timestep, and initial conditions can be tuned to give a wide variety of research possibilities from cosmological to dwarf galaxy scales. By considering one or two galaxies at a time, the simulation is able to go into high resolution collision dynamics. Unfortunately, it is often still too computationally expensive for PC N-body simulations to include the Interstellar Medium, gas infall, etc.

Gadget : The Simulator

The simulation used here is GAlaxies with Dark matter and Gas intEracT, or GADGET2- originally developed in 2000 by Volker Springel and updated in 2005. (4) It is an N-body and Smooth Particle Hydrodynamics (SPH) simulation library used for galaxy collisions, galaxy clusters, hydrodynamical simulations of cosmological structure, and cosmological simulations of the local universe. GADGET2 is massively parallel, and for the galaxy collision simulations, will evolve a set of initial conditions (ICs) under collisionless self gravity.

Starscream : Creating Initial Conditions

"Formerly a scientist and a graduate of the Cybertron War Academy, Starscream is a treacherous high-ranking Decepticon who turns into a jet, and desires to replace Megatron as the leader of the Decepticons."

- Wikipedia

Since Gadget takes in initial conditions in a binary file, creating initial conditions with different galaxies aside from the base example is difficult. Hence, we turned to Starscream, which provided code for allowing one to more easily generate galaxies with different parameters and outputting in a Gadget compatible format. Starscream was developed by Jay Jay Billings in 2008.

The approach can be classified as having three steps : Firstly, determining the properties of the galaxies and having a model. Secondly, We represent the galaxy as a collection of particles, so we have to generate an appropriate number of particles and assign them properties that match the model. Lastly, after creating two galaxies, we can put them on some kind of collision path.

Method

Using Starscream, we are able to produce a Springel-Hernquist type of galaxy with a stellar disk and a dark matter halo. The dark matter halos follow a Hernquist distribution (Hernquist, 1900) and a Navarro-Frenk-White profile (Springel & White, 1999). The stellar disk is modelled as an exponential disk and follows Springel & White.

Particles are created and assigned positions and velocities to match these models. Positions are assigned using the Metropolis-Hastings algorithm, which is a Monte Carlo Markov Chain Method. Each particle's position only depends on the previous particle's, and the dependence is based on the probabilistic distribution we want to match (Markov Chain). A move to a more likely state is always accepted, but a move to a less likely state is only accepted with some probability. In this way, after many many particle positions are assigned, we converge on the desired distribution (Monte Carlo). For velocities, the velocity dispersion is calculated and then the positions drawn from a normal distribution for a realistic velocity distribution. Finally, the galaxies are put on a parabolic collision path.

Using this, we created four different galaxies by varying two parameters. We have our base galaxy which comes from the original galaxy provided as an example. We then lower v200, the virial velocity, to get a galaxy which is much smaller : less massive, smaller stellar disk, and smaller halo. We also vary lambda, the spin parameter, which only varies the size of the stellar disk of the galaxy, to get another two galaxies.

The following are the galaxy parameters:

No. of disk particles: 10000 No. of halo particles: 20000

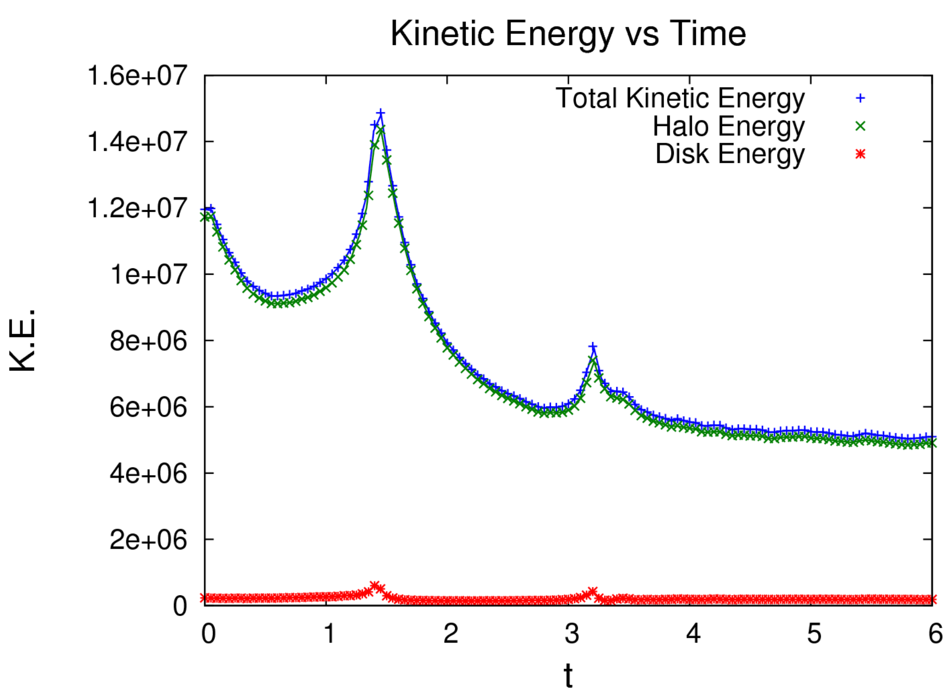
Base: The total mass of this galaxy is 2.667152e+45 grams. Disk mass: 6.667880e+43 g Halo mass: 2.600473e+45 g The virial radius of this galaxy is 225.352113 kpc. Disk scale length: 2.721830 kpc Halo scale length: 15.023474 kpc Halo 'a' parameter = 28.781532 kpc	Low v200: The total mass of this galaxy is 2.667152e+42 grams. Disk mass: 6.667880e+40 g Halo mass: 2.600473e+42 g The virial radius of this galaxy is 22.535211 kpc. Disk scale length: 0.435423 kpc Halo scale length: 1.502347 kpc Halo 'a' parameter = 2.878153 kpc
High lambda: The total mass of this galaxy is 2.667152e+45 grams. Disk mass: 6.667880e+43 g Halo mass: 2.600473e+45 g The virial radius of this galaxy is 225.352113 kpc. Disk scale length: 6.792712 kpc Halo scale length: 15.023474 kpc Halo 'a' parameter = 28.781532 kpc	Low lambda: The total mass of this galaxy is 2.667152e+45 grams. Disk mass: 6.667880e+43 g Halo mass: 2.600473e+45 g The virial radius of this galaxy is 225.352113 kpc. Disk scale length: 1.695307 kpc Halo scale length: 15.023474 kpc Halo 'a' parameter = 28.781532 kpc

Results

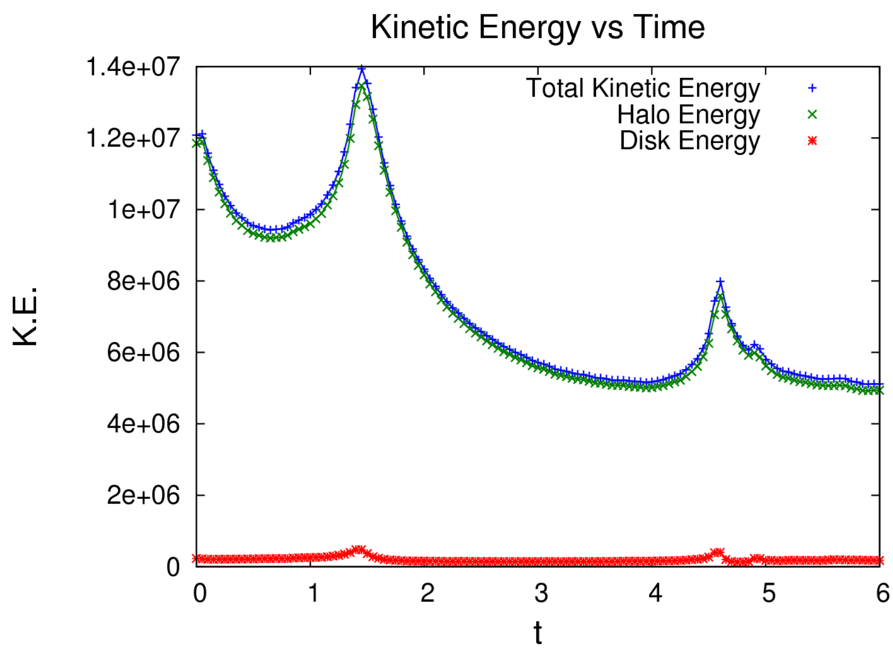
The results of the simulation are videos that can be found at
https://www.youtube.com/playlist?list=PL44jVipt-Qaf5XVicXTTMzJgKJQ-BXevh

We also plotted the kinetic energy over time for all the simulations, and the plots can are shown below. We ran simulations of colliding all possible combinations of the four galaxies and also with the base case at several starting distances. When increasing the starting distance, the length of time between successive fallbacks increases. Hence, if they started far away enough, it is possible that they would overshoot each other. For the rest of the collisions, the only notable different case is that of the base galaxy with the small halo galaxy. In this case, it appears that the smaller galaxy radially plunges into the big galaxy and its structure disintegrates, shooting out the other side.

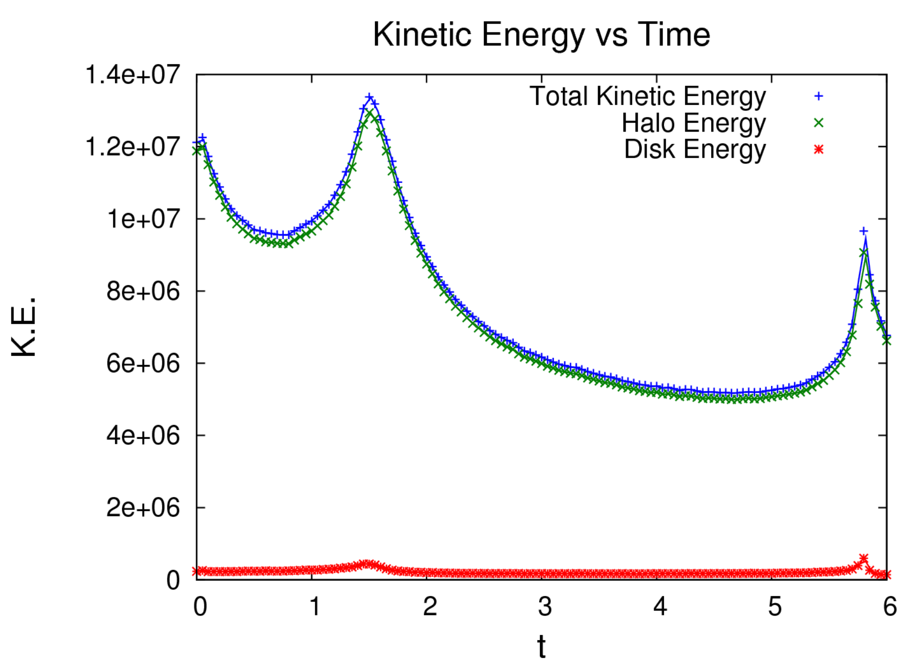
Base-Base (Near)



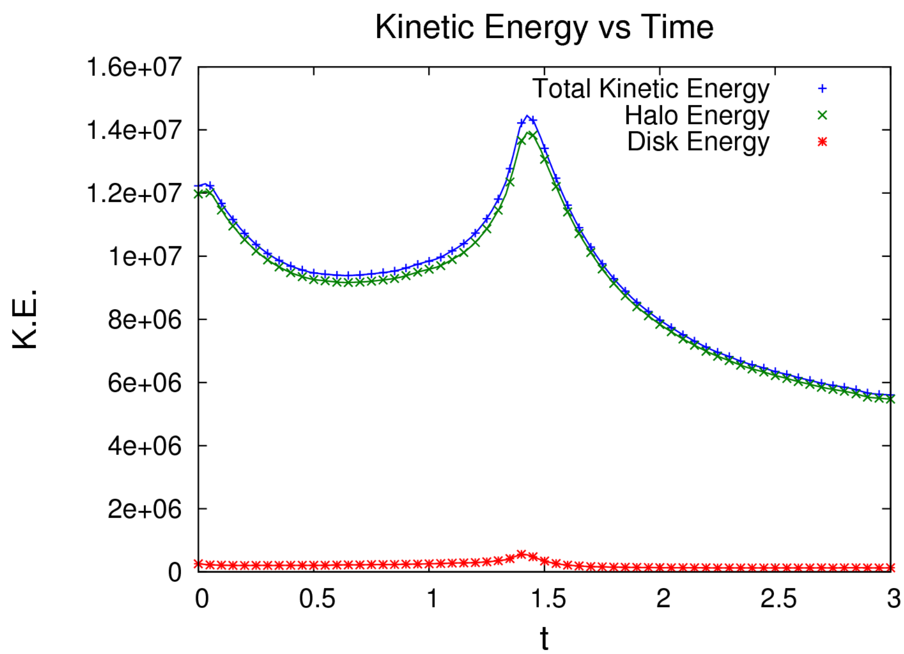
Base-Base (Medium)



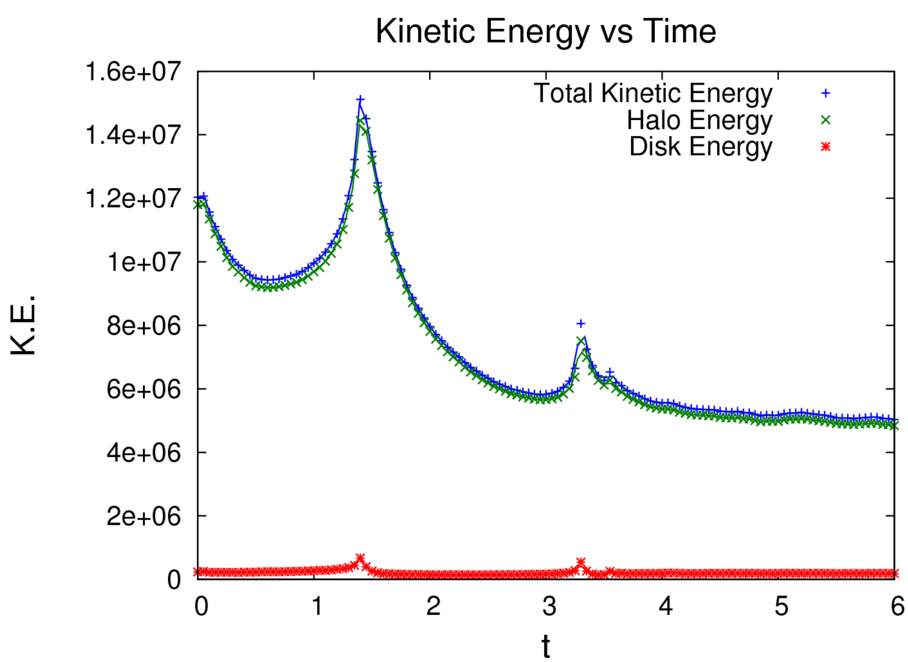
Base-Base (Far)



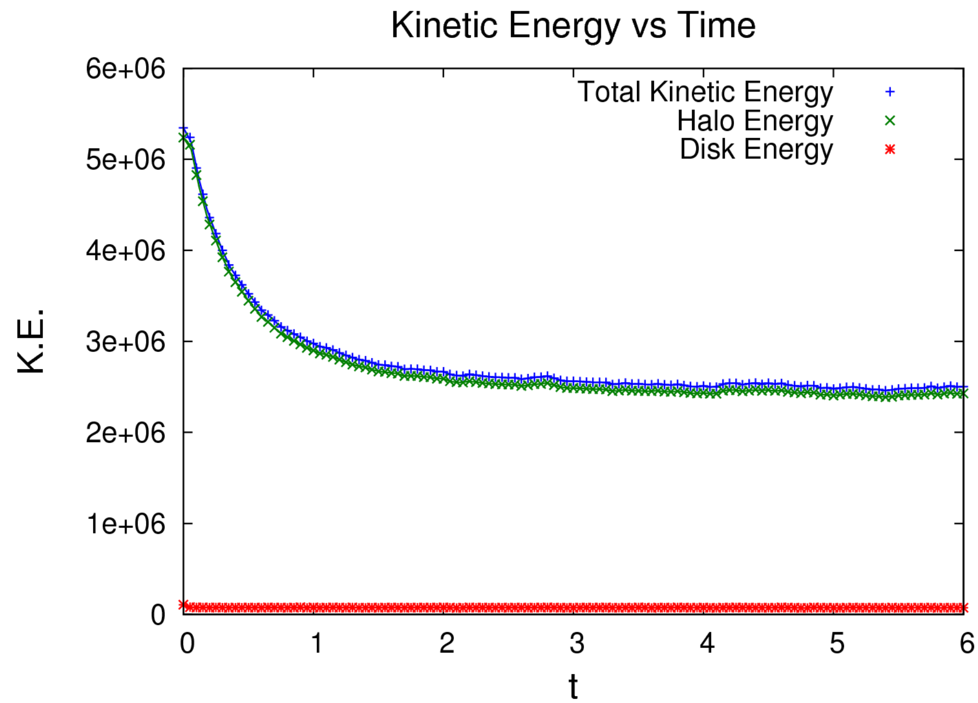
Base-High Lambda



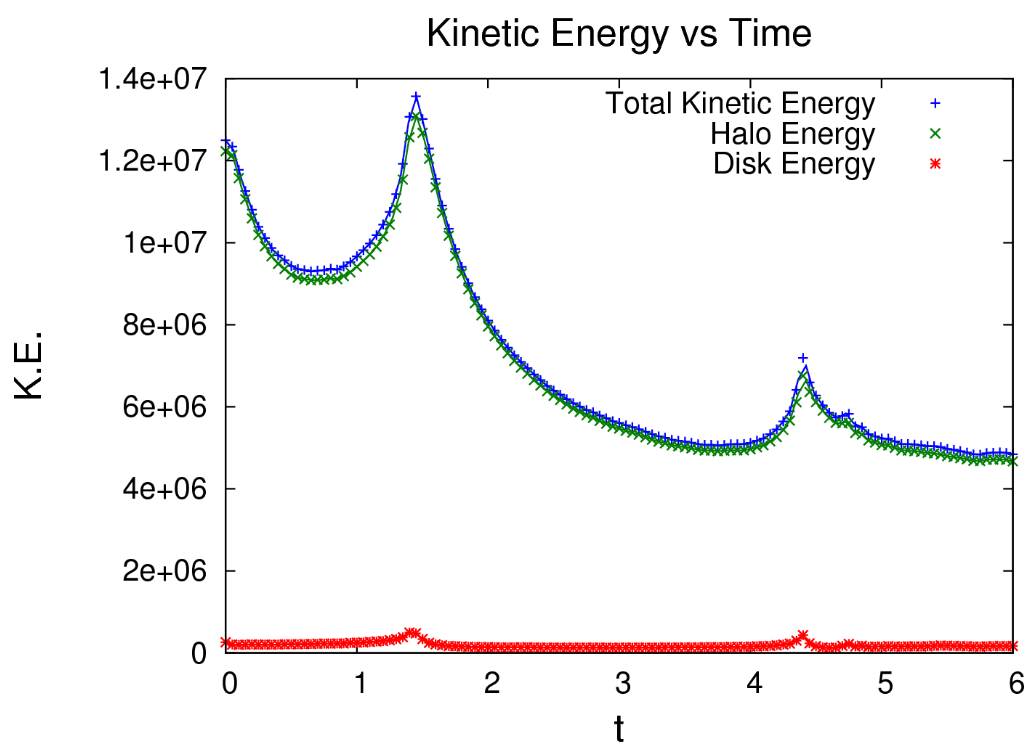
Base-Low Lambda



Base- Low v200



High Lambda - High Lambda



Possible Extensions

Further work could be done in the following areas:

1. Include Bulge, Gas Components

   In reality, the dark matter halo and the stellar disk are only two components of a basic galaxy structure. The other two components that were not modelled are the galactic bulge and the gas in the galaxy. Since Gadget is an SPH simulation, it supports the simulation of evolution of the gas component.

2. Run Simulations for much longer timeframe

   All the simulations were run for a fixed number of timesteps. Ideally, the simulation should run until a steady state, most likely being when the merger is complete or possibly the galaxies have passed each other.

3. Consider different collision orbits

   We only considered one type of collision orbit : the parabolic one. The effect of different orbit paths might be interesting to look at.

4. Consider Multi galaxy collisions

   Currently, only two galaxies are being collided at the moment. While multi galaxy collisions are extremely rare, it would be fun to see how these would look like.

5. More Data analysis

   When analyzing the data, we only look at the kinetic energy of the galaxy, in addition to the distribution of position and velocities of the particles. More data could have been extracted from the simulation and more analysis carried out.

CONCLUSION

In conclusion, we find that the disk size of the galaxy seems to have little consequence in affecting the process of the collision. Rather, the halo size is much more important and results in a very different looking collision.

REFERENCES

1. Smithsonian Astrophysical Observatory. (2013, April 04). Galaxy Collisions. Retrieved December 10, 2016, from https://www.cfa.harvard.edu/news/su201313
2. Struck, C. (1999, August 24). Galaxy collisions. Physics Reports, 321(1-3), 1-137. doi:10.1016/s0370-1573(99)00030-7
3. https://github.com/jayjaybillings/starscream
4. https://wwwmpa.mpa-garching.mpg.de/gadget/