The search for binary systems in tidal tails from galaxy mergers

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Abstract

We present the preliminary results of the search for binary systems of ejected stars from galaxy mergers. As well as the search for binary systems in the tidal tails of merging galaxies. We discuss the impact of initial conditions on the amount of ejected stars during galaxy interaction. We predict that a higher initial relative velocity between the galaxies will result in a higher number of ejected stars. Furthermore, we looked at tidal tails of galaxies that completely merge or pass each other and stay unbound. We find a handful of stable binary systems, a triplet and a quadruple system in one of our searches.

1 Introduction

One of the features of the current cosmological model (ΛCDM) is its theory on formation of structures in the universe. We know from observations that structures like galaxies grow in size by merging with other galaxies. The merging of galaxies occurs everywhere, from large galaxies capturing small structures to major mergers of massive galaxies like our own Milky Way and Andromeda.
Galaxy interaction can be clean (like a low velocity merger), but they can also be destructive (like the bullet galaxy). A destructive interaction can partially destroy the structure of the passing galaxies, which results in the ejection of matter in the form of stars. Most of the stars have velocities that do not exceed the escape velocity of the merger, but if they do they are unbound from the merging galaxy and continue their path through the universe on their own.
During these mergers, many stars are ejected. This raises the question: Is it possible for ejected stars to form a binary system that is unbound to the galaxy merger? Furthermore, another point of interest is the tidal tail that is created when the galaxies collide under an angle. The second question that is raised is therefore: Is it possible for stars in the tidal tail to form a binary?

The capture of stars to form a binary star system has been described by Tohline (2002)[7]. Here is described that binary stars can form from the relatively simple mechanism of capture. However, purely gravitational encounters are rare resulting in only few binaries. Described by Tohline (2002) is that for two unbound stars to form a binary a dissipation of the energy is needed. This dissipation of energy can occur by energy transfer of both unbound stars to a third unbound star. The third star then remains unbound and the other two stars form a binary star system. In this work we believe that this is not the case, but the moving away of the joint potentials of the two galaxies will do the trick.

In this project we analyse unbound binary formation by looking at simulations of a galaxy merger using the AMUSE code[3][4][5]. This code is useful for initializing the galaxy merger and calculating the evolution, of the positions of the individual galaxies, in time. Furthermore, we will look at different initial conditions of the galaxy merger. This gives us insight in what conditions have to be met to, firstly, have unbound stars and, secondly, have binary formation between unbound stars.

We describe the methods in section 2. In section 3 we present the results which are discussed in section 4. Finally, the conclusion is provided in section 5.

2 Methods

This section will describe the search for binary systems in the tidal tail of a galaxy merger. It will be divided in three parts. The first part describes the setup of the galaxies and evolution over time in general. The second part shows the evolution of galaxies for with two specific goals: the search for unbound particles, and the formation of tidal tails. The last part describes the search for binary systems and the methods involved.

2.1 Model initialization and Evolution

To setup the system, we used the GalactICs[2] code to model galaxies with a mass of $10^{12} M_{\odot}$, and set the Dark Matter halo to a radius of $\approx$200 kpc. The galaxies are initialised with a specific number of particles for the Dark Matter halo, the Stellar Disk, and the Stellar bulge. The ratio of the particles is always 2:1:1, and the number of particles used for a model will be described in the individual sections.
During this research, we made use of two types of gravity solvers: BHTree [1] and Gadget2 [6]. The gravity solvers calculate the force of each particle on each particle in the model. These two solvers have in common that they are tree-codes, which means that they regard particles that are far away as indistinctable. In other words, if you calculate the force exerted on a particle you can treat particles that are far away, yet close to each other, as a single particle with a mass as sum of the individual masses. This way you have to do less calculations and the code is faster. This procedure is less accurate, but it has little impact on a system so large as galaxies.

The difference between the two codes is that Gadget2 is a hydrodynamics code, which can be used for gravitational problems, whereas BHTree is a gravity code. Gadget2 is a more simplistic code in the sense that it does not take as much higher order force terms as BHTree, therefore Gadget2 is faster, but slightly less accurate. The choice for gravity solver for individual models is explained in their individual sections.

2.2 Investigating initial conditions

In this section we will describe the initial conditions for the galaxy mergers. We will first discuss the initial conditions for the search of ejected stars, and afterwards we will discuss the initial conditions for galaxy mergers that have formed tidal tails.

2.2.1 The search for ejected stars

Our first goal is to find particles that have been ejected in the aftermath of a galaxy merger. We setup 2 galaxies with a mass of $10^{12} M_\odot$ and a total of 40000 particles each (ratio of components can be found in section 2.1). The galaxies are then separated by an initial distance, and one of the galaxies is rotated 90° on the y-axis. The initial relative velocity and position is given in table 1.

scenario	$x_{rel}(kpc)$	$y_{rel}(kpc)$	$v_{x,rel}(km/s)$	$v_{y,rel}(km/s)$
1	400	0	-100	0
2	400	0	-500	0

Table 1: The initial conditions for two scenario's of galaxy mergers.

We are interested in the movement of individual stars within these galaxies. Therefore, we setup massless tracer particles that follow the same distribution as the galaxies they inhabit. We initiate the tracer particles in the same way as the galaxies, but only select the stars from the galactic bulge and disk, and set their mass to zero. Since the total number of initiated stars is low compared to the mass of the total galaxy we can assume that the initiated stars have negligible mass. However, since these massless stars can not interact with the 'real' galaxy we have to bridge both initiations. For this the AMUSE community code 'Bridge' is used, this makes it so that the massless stars still feel the gravity of the real galaxies. The model is then evolved for 7 Gyr with a timestep of 1 Myr using the BHTree code, since Gadget2 is incompatible with Bridge.

The first scenario described in table 1 is a scenario of a soft merger of galaxies that collide head on. This means that the galaxies are aligned and the only initial velocity is added in the direction of the other galaxy. The velocity is chosen low to make sure that the galaxies eventually merge. The second scenario is a head-on collision of the galaxies, but the difference with the soft merger is the initial velocity. The initial velocity is chosen in such a way that the galaxies can (partially) destroy each other when they pass.

2.2.2 The search for tidal tails

The second goal is to search for binaries in tidal tails of galaxy mergers. We thus need to setup initial conditions to find mergers that create clear tidal tails in the galaxies when they interact. In the previous section we described mergers with head on collision that do not create these tails. In order to create the tails, we need that particles in the outer part of the galaxies are broken from symmetry with the rest of the galaxy. This means that the outer part needs an increase in rotational velocity such that it breaks in a stream of particles the follow the inner part of the galaxy. This is achieved by adding additional spin to the galaxy, which during the merger is achieved if one of the galaxies spirals around the other instead of a head on collision. This spiraling is achieved by adding a initial velocity in another direction then the separation. In this case we only have a separation in the x direction, and thus we add an additional velocity in the y direction. The initial conditions for two scenarios are given in table **??**

scenario	$x_{rel}(kpc)$	$y_{rel}(kpc)$	$v_{x,rel}(km/s)$	$v_{y,rel}(km/s)$
1	400	0	-300	45
2	400	0	-100	40

Table 2: The initial conditions for two scenario's of galaxy mergers.

These scenario's are setup with galaxies with many more particles as in the previous section since we are not interested in individual stars that become unbound, but rather for binary systems of massive particles. This means that we can use Gadget2, which has much faster computational time and thus allows for many more particles to be used. Since The models are evolved for roughly 6 Gyr, which is long enough for the tidal tail formation, and the fall back of these particles back into the galaxy.
Table 2 show again two scenarios. The first of two galaxies that will merge and with a stable tidal tail for several 100 Myr before merging. The second scenario is of two passing galaxies that do not merge, but their interaction creates a stable tidal tail in one of the galaxies. The resulting evolution of the galaxies will be discussed in sections 3.2 and 3.3

2.3 Binary classification

In this project we are interested in the formation and destruction of binary systems. First we look at these systems that become unbound of the merger and afterwards we look at such systems within the tidal tail of the galaxy merger. The identification of stars that are or become unbound is done using the following condition:

$$v_{star} > v_{esc} = \sqrt{\frac{2 * G * M}{r}} \tag{1}$$

Here G is the gravitational constant taken to be $6.67 \times 10^{-11} m^3 s^{-2} kg^{-1}$, M is the mass of the merged galaxies and r is the distance between the star in question and the center of mass of the merged galaxies. This condition states that for a star to become unbound it has to have a velocity that is greater than the necessary escape velocity. The identification of stars that are within the tidal tail is done by using a snapshot of the merger where the tidal tail is clearly visible and selecting all the stars that are present in the tail at that time.

After identifying the stars in question, unbound or within the tail, we can look at what stars form a binary. This identification is for unbound stars as well as for stars in the tidal tail the same. After we have obtained a set of stars that follow these conditions, for being unbound or being in the tidal tail, we look at if two stars have an encounter that is closer that 100 parsec. Depending on the size of the data set we also state how often this close encounter has to happen. For example, for a data set with relatively little data points this only has to happen once, because they are not very likely to pass each other.

Of the stars that have such a close encounter, a distance plot is made to see their separation during the merger. The two stars that have a close encounter are then visually identified as a binary candidate if the plot shows a sinusoidal-like course with multiple maximums. Furthermore, these maximums have to be at least lower that 500 parsec, otherwise the encounters might as well be coincidental. To further confirm if the sinusoidal-like course indicates that the two stars form a binary we the look at a plot with both the relative velocity as well as the relative distance on the vertical axis. If one of the graphs has peaks where the other has troughs, and the other way around, the two stars are considered a binary.

3 Results

In this project we looked at two different phenomenon that could result in the formation and destruction of binary systems. Therefore, this section is split into three parts, the first part will be about unbound stars and the second and third part will be about the tidal tails, with the difference being the amount of data points in each galaxy.

3.1 Unbound stars

3.1.1 Initial conditions

Since unbound stars as a result of a galaxy merger is a rare phenomenon we first started by looking at optimal conditions. These are chosen such that more stars are getting unbound as a result of the merger. The initial conditions that were used to compare results are depicted in table 3. In words this table describes two head-on collisions (scenario 1 and 2) and two collisions where the galaxies more or less spiral around each other (scenario 3 and 4). The purpose of the relatively small velocity in the y-direction is to more or less have the two galaxies spiral around each other before merging.

scenario	$x_{rel}(kpc)$	$y_{rel}(kpc)$	$v_{x,rel}(km/s)$	$v_{y,rel}(km/s)$
1	400	0	-100	0
2	400	0	-100	10
3	400	-100	-100	0
4	400	-100	-100	10

Table 3: The initial conditions for four scenario's of galaxy mergers.

The scenario's in table 3 are run with a relatively small amount of particles to improve computation time; 2000, 1000 and 1000 for the halo, bulge and disk respectively. This resulted in the scenario's 3 and 4 both having no unbound stars. Scenario's 1 and 2, however, both show a single unbound star. Remarkable from scenario 2 is that the star is being shot out of the merger after the two galaxies forming a single object, whereas the unbound star from scenario 1 got unbound during the impact. However, this does seem like the best condition for stars being unbound is a head-on merger.

3.1.2 Mergers

In order to find binaries of ejected we need to determine which merger ejects the most stars. To determine this we compare 2 mergers with different initial conditions and look at the position of the particles of the merging galaxies. From their xy and xz positions we can determine if particles (or stars) are ejected from the merger. We plot positions of the mergers at different times:

1. Initial timestep
2. First approach before encounter
3. First encounter
4. After encounter
5. Second Encounter (if applicable)
6. Final timestep

The plots are shown on the last pages. Figure 1-3 display the first scenario, and Figure 4-6 display the second scenario [1]. We can see that no particles are ejected in either of the scenario's, but we have to take into account that the particles each have $\sim 10^6 M_\odot$ and thus have a mass that is much larger than

[1] movies of the merging galaxies can be fount at https://github.com/kappie07/Team_A, or send an email roewen@strw.leidenuniv.nl

actual stars. We can see some particles that move away from the center for a while, but are still bounded to the system. We expect our test particles to become unbound in such a situation.
As we predicted, the first scenario displays a soft merger that shows little structure change during the merger. We therefore do not expect many particles to be ejected during the merging of the galaxies.
The second scenario displayed the fast approaching galaxies, which do not merge, but only pass through each other. We can see slightly more structural change, especially in the top panel of figure 6 (after 1.1 Gyr). We expect that this is a point where stars get ejected, and thus expect some tracer particles to become unbound which we can trace to look for a binary system.

Binary search

We have not been able to find unbound stars, and thus have not been able to classify binary systems.

3.2 Tidal tails with little data points

In this section the results of the first situation of the tidal tail are presented. This situation has the galaxies, each consisting of 500,000 data points, at a separation of 400 kpc, a velocity of 300 km/s in the direction of the separation as well as a velocity of 45 km/s orthogonal to this direction. With these initial conditions the galaxies pass each other and interact forming a tidal tail. However, through the high initial velocity the galaxies do not merge and stay unbound from each other, without exchanging a single star.

3.2.1 Identification of the tidal tail

After obtaining the data of the galaxy merger we can start by identifying the tidal tail. This is done by looking at a time frame where the tidal tail seems to be almost stationary, in between formation and relapse. Fig. 1 shows the galaxy that has formed a tidal tail, as well as the cut-off condition we used.

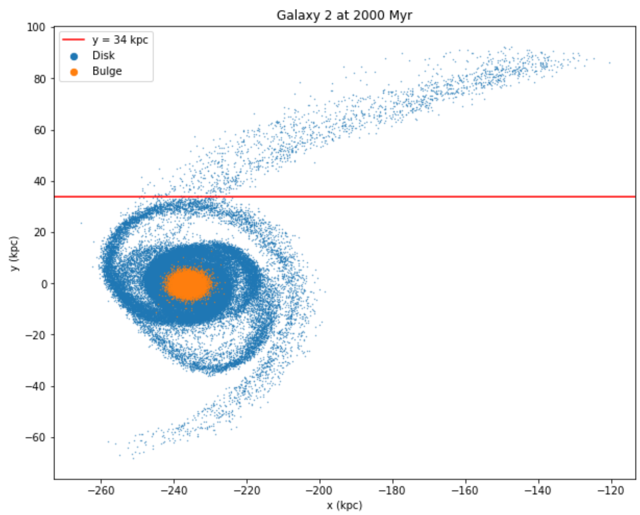

Figure 1: This plot shows the galaxy that has formed a tidal tail as a result of passing another galaxy. The red line represents the cut-off, everything above that line we consider part of the tidal tail.

In Fig. 1 we consider all stars with a vertical position higher than the red line as part of the tidal tail. These 1597 stars is what we will track along the evolution of the merger, from initialization to relapse of the tidal tail. Note that this situation also creates a tidal tail at the bottom side of the galaxy, however, since the tidal tail on the top is more stable we decided to focus on this tail only.

3.2.2 Identification binary candidates

After obtaining the stars which will, at some point, be part of the tidal tail we look at if two stars have an encounter closer than 100 parsec. This resulted in 250 unique encounters between two stars in the time frame of the formation and relapse of the tidal tail. Many of these unique encounters only had a single encounter closer than 100 parsec and thus did not qualify as binary. Some plots, however, show multiple encounters closer than 100 parsec, Fig. 2 is such an example. In this figure we clearly see a sinusoidal-like pattern between the 1500 Myr and 3500 Myr.

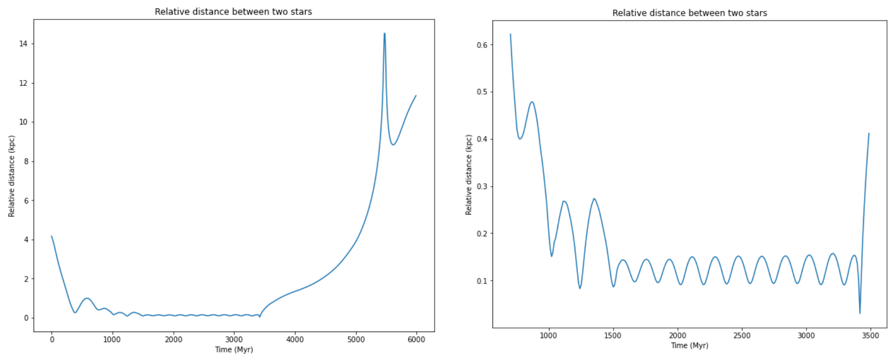

Figure 2: On the left we see the relative distance between two stars during the whole merger. On the right we see the same plot, only this time it is zoomed in on the suspected formation and destruction of the binary.

To be completely certain this specific sinusoidal-like pattern is due to a binary system, we also plot the relative velocity, which can be seen in Fig. 3. In this figure we can clearly see that the peaks of the relative velocity and the troughs of the relative distance happen at the same time. Judging from this figure we then state that these two stars form a binary around 1500 Myr and this is destroyed around 3400 Myr. Using this method we obtained 7 similar graphs, some being stable, some being unstable.

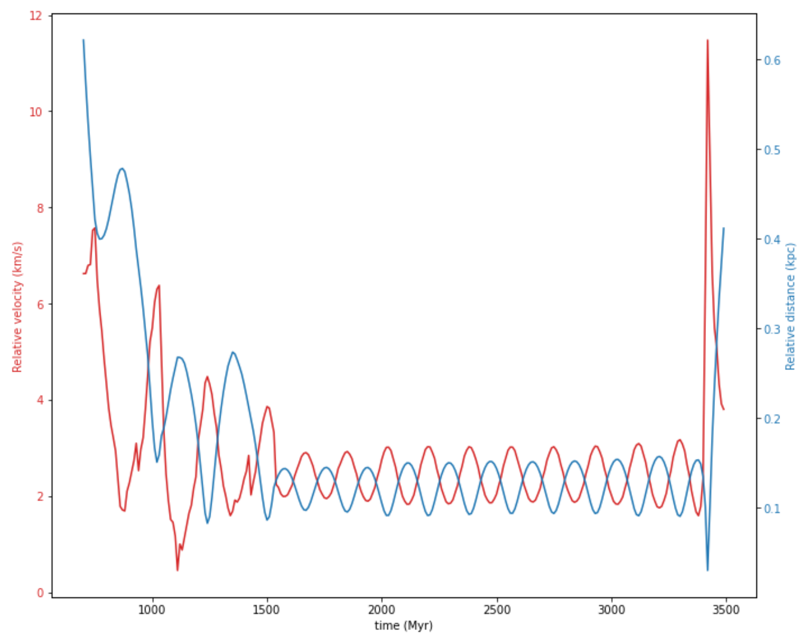

Figure 3: The relative velocity and the relative distance between two stars over time.

Furthermore, not only did we find such pattern with two stars, we also found cases with multiple stars showing such a pattern, this is shown in Fig. 4. These multiple star systems were found because the id of one of the stars had an encounter closer than 100 parsec with multiple other stars. In both plots of Fig. 4 we see a somewhat distorted sinusoidal-like pattern of the graphs. We suspect that this is from the interaction of multiple stars, it is no longer near perfect sinusoidal like in Fig. 3. However, to visualize this in a single plot is quite difficult. That is why we chose to do this by creating a video centered around the center of mass of the stars in question. If this system is then a multiple star system they should circle around each other, snapshots of the video[2] are visible in Fig. 5. From these snapshots it is not clear that the four stars stay bound, but they are. What we can obtain form these plots is that the structure of four stars switches, going clockwise, we see that the red and green stars changed places. This indicates that the stars are turning around each other and not moving as a whole, without interacting.

3.2.3 Binary system data

Taking all this into account we obtain the information in Table 4 and Table 5. The data in these tables is obtained by looking at the relative distance and

[2]Full video can be accessed via: https://github.com/kappie07/Team$_A$

relative velocity plots of the systems, it is therefore not quite accurate, but the best we can do at the moment. Furthermore, a lot of the data is really hard to determine, for example, the data of multiple star systems. These systems are quite unstable, their relative distance peaks, relative distance troughs and periods constantly change and is thus hard to estimate. It therefore is also hard to pinpoint when the stars are bound to each other and when they become unbound.

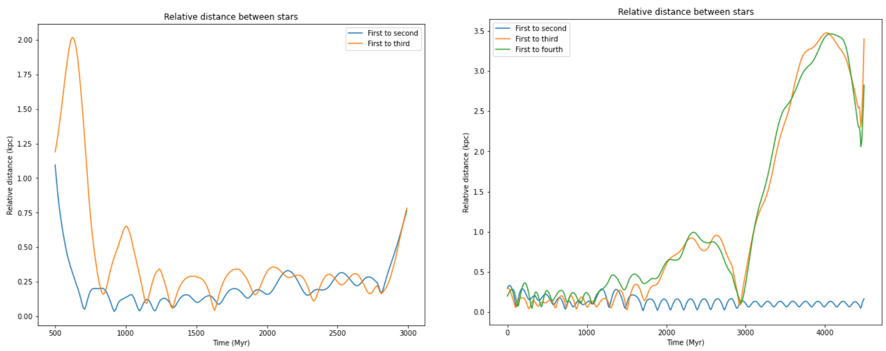

Figure 4: On the left we see two different distance graphs, because of the similar shape and size we suspect this is triple star system. On the right we see three different distance graphs, because of their similar shape and size we suspect this is a quadruple star system.

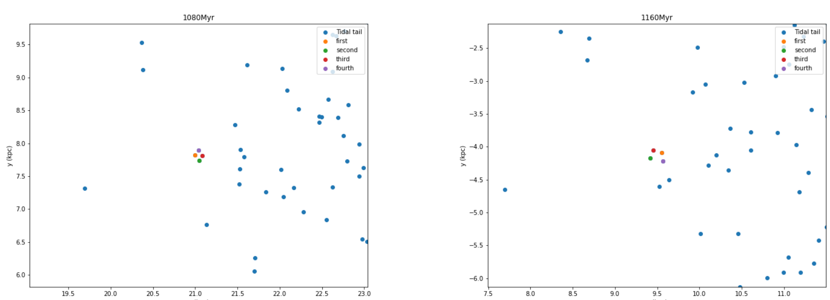

Figure 5: In this figure we see two different time frames of the same four star system.

Table 4: Information about the binary systems. Here * indicates that there is disturbance in one of the orbits, in this specific case it seems to delay its orbit by half a orbit worth of time. This results in having a time frame of 8 orbits, but only orbitting 7.5 times. Furthermore, $^{+}$, means that the binary is relatively unstable in period, pericenter and apocenter. Finally, note that number 4 has two separate entries, this is because these two stars formed a stable binary at two separate times.

Number	Time of formation (Myr)	Duration (Myr)	Period (Myr)	Pericenter (pc)	Apocenter (pc)	Number of orbits	Absolute velocity during formation (km/s)	Absolute velocity during separation (km/s)
1	1575	1800	~180	90.4003	157.199	10	264.5	446.9
2	1370	1800	~220	26.9018	229.831	~8.2	262.6	373.6
3*	2390	2090	~261	84.7942	245.327	~7.5 (8)	138.4	245.9
4.1	350	640	~160	76.7970	188.682	~4	225.1	348.4
4.2	1870	4130 +	~780	30.6289	595.507	~5.2	227.3	-
5	1340	1090	~145	52.5882	121.027	~7.5	227.5	417.4
6^{+}	1230	1460	~292	43.6168	316.078	~5	135.0	246.8
7^{+}	1080	1160	~232	84.5494	216.775	~5	247.8	372.2
8^{+}	1270	770	~257	28.0525	407.823	~3	203.1	389.1

Table 5: Information about the multiple star systems. Note that all these systems are mostly unstable.

System	Time of formation (Myr)	Duration (Myr)	Absolute velocity during formation (km/s)	Absolute velocity during separation (km/s)
Triple 1	~850	~2050	537.2	234.3
Triple 2	~690	~3410	506.6	599.0
Triple 3	~500	~1800	147.2	240.7
Quadruple	0	~1800	390.6	257.0

A point of interest of ours is the time of the formation. From the whole galaxy merger we know that they first pass each other around 1000 Myr. The tidal tail then starts to form clearly around 1300 Myr and becomes somewhat stable around 2000 Myr. Around 3500 Myr the last remnants of the tidal tail start to relapse and after 5500 Myr only a handful of stars remain on the old position of the tidal tail. Comparing these time frames to the time of formation binaries and multiple star systems we see a few things. Multiple star systems are created before the two galaxies have their actual first encounter. The multiple star systems then seem to survive the initial formation of the tidal tail but are destroyed somewhere during the relapse. The binary systems show a somewhat different formation than the multiple star systems. Most of the binaries are created between the first encounter and the tidal tail becoming stable and are then, like before, destroyed during the relapse of the tidal tail. However, the most striking thing is that the binaries formed around the time of the stable tidal tail seem to have a longer lifespan, one still exists after the, almost, total relapse of the tidal tail.

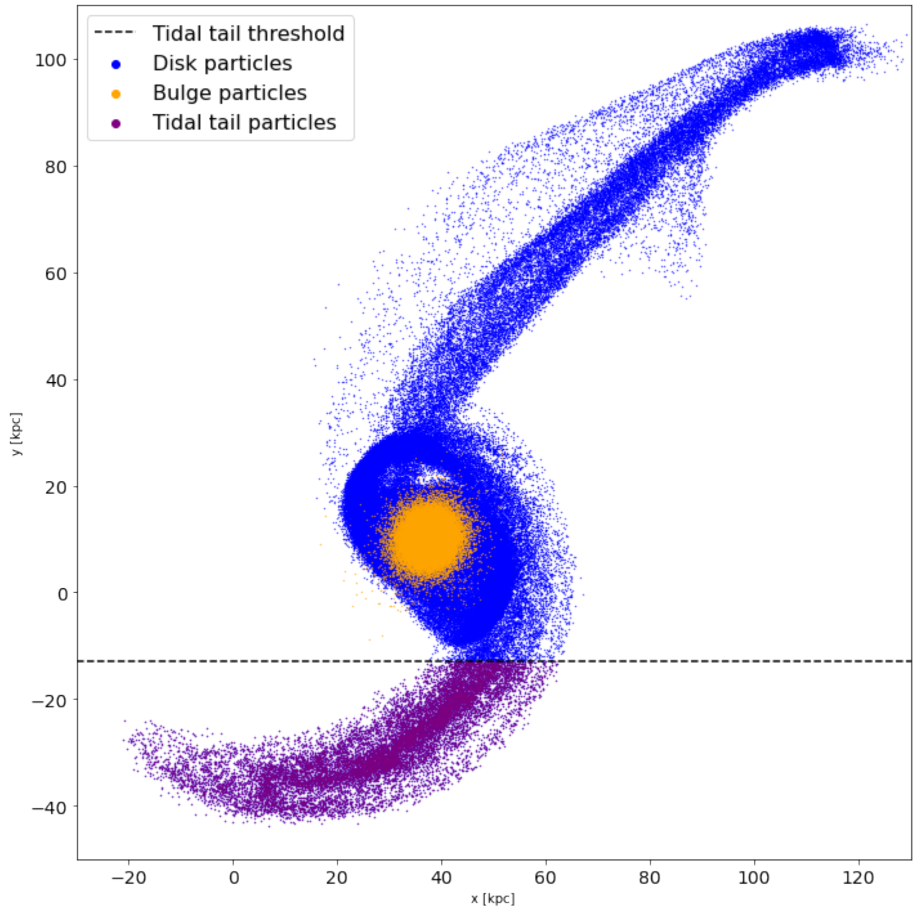

Figure 6: Stable tidal tail, in blue the disk particles, in orange the bulge particles, and in purple the particles that belong to the tidal tail.

3.3 Tidal tails with more data points

This section discusses the results of the second situation of the search for binaries in the tidal tail as found in table 2. The model consist of two galaxies, each with 2 million particles, and a separation of 400 kpc in the x direction, a initial relative velocity of -100 Km/s in the x direction and a relative velocity of 40 Km/s in the y direction. **check deze zin** Figures **??** - **??** show the merging galaxies at multiple important times: initially, time of first encounter, stable tidal tail and the second encounter. We can see a clear tidal tail that has formed around 2100 Myr, and has a low velocity around 2500 Myr. At this time we classify particles of the tidal tail by setting a threshold, which is displayed in figure 6

This threshold results in 16025 particles in which we search binary systems.

3.3.1 Identification of the tidal tail

In this section we report the results of our binary search for particles in the tidal tail for a merging pair of galaxies. As mentioned in section 3.3 we define the particles of the tail of interest as particles below a threshold at a time of 2500 Myr in the simulation. From figure 6 we can see that there are 2 tidal tails, on the top and on bottom of the galaxy. We chose to investigate the bottom one only since the top tail is interacting with the galaxy (which is shown in figure **??**) and thus is not a stable environment that as we would like.

As mentioned in section 2.3we are searching for binaries by looking at their separation over time. We define a binary candidate as such if the two particles have encountered each other within 100 parsec in the time that the tail exists, which is between 2300-3000 Myr. We have positions and velocities every 10 Myr for each of the particles, which leads to 71 distances per two sets of particles. This however leads to a large set of candidates, many of which encounter one another for a brief period of time and never truly interact. We thus reject candidates that were within 100 parsec for 10 or less points in time. This leads to 28 binary candidates that were within 100 parsec for more then 14% of the time spend in the tidal tail. These candidates were manually inspected by looking at their separation over time and we have determined that we found 12 binaries that show high clear features of a binary system. We tabulated some features of the binaries in table 6, and show an example of a binary system in figure 7

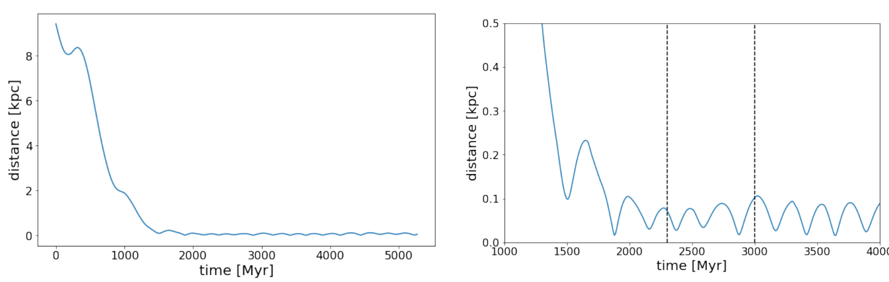

Figure 7: On the left we see the separation between the two particles during the simulation, and on the right we see a zoomed in version of the same separation. The right plot shows boundary time of 2300 and 3000 Myr, which indicate the stable time of the tidal tail.

From figure 7 we can see that the candidate system starts its first orbit around 1900 Myr, and is a clear binary ever since. To give more insight in this seemly periodically movement we show the relative velocity aside the relative distance over time in figure 8. We can see that the relative velocity is highest at pericenter, and the lowest at apocenter. This shows that the system is orbiting each other periodically.

From figure 7 we can see that the orbits shape is similar every time, but it does change. This indicates that other particles influence the binary system

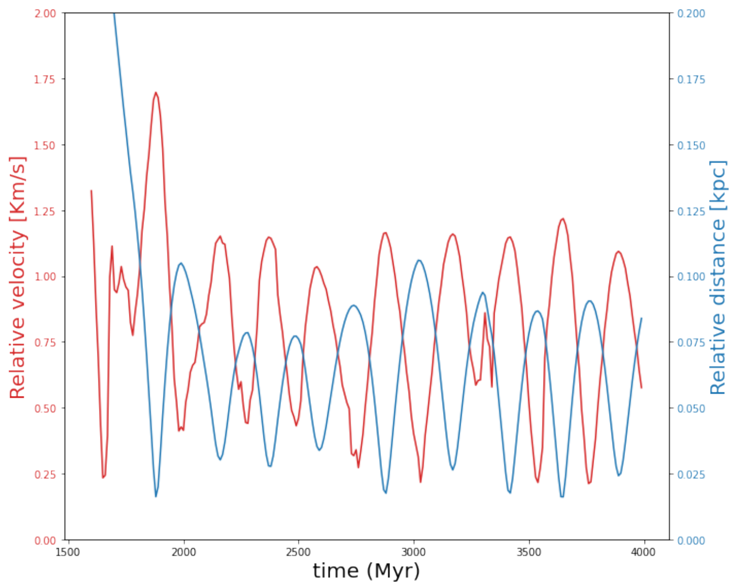

Figure 8: The relative velocity and relative distance over time.

heavily, and cause instability by passing close by.

Table 6: Information about the binary system. Binary 5 has a clear distinction between 2 different stages in its lifetime. The first and second values for the peri- and -apocenter describe different orbits.

Number	Time of formation (Myr)	Time of Separation (Myr)	Period (Myr)	Pericenter (pc)	Apocenter (pc)	Number of orbits	Absolute velocity during formation (km/s)	Absolute velocity during separation (km/s)
1	2440	-	~330	~ 42	~ 150	> 8	240.4	-
2	1780	3000	~330	~ 73	~ 136	4	361.5	247.0
3	1960	3680	~242	~ 10	~ 76	7	444.3	240.0
4	2000	3150	~ 287	~ 65	~ 144	4	427.4	-
5	1950	-	~ 225	~ 50/~ 32	~ 90/~ 158	>11	429.2	-
6	1510	-	~250	~ 72	~ 134	>12	317.3	-
7	1460	-	~400	~ 71	~ 230	>11	161.03	-
8	1880	-	~250	~ 16	~ 90	>13	411.7	-
9	1330	4860	~285	~ 10	~ 150	12	317.0	351.9
10	2390	3340	~317	~75	~159	3	285.7	349.6
11	1930	-	~285	~48	~ 135	>10	407.6	-

Each of the binaries discussed here are very easily influenced by forces from other particles. Therefore, we can even see in a stable example like figure 7 that the apocenter, and pericenter distance change a lot over time. This is why the values in table 6 are stated as similar values, and can not easily be set for every orbit of the binary system. We can say however that the binaries were formed just before, or just after the encounter of the two galaxies, and only two that were formed in the tidal tail itself (between 2300 and 3000 Myr). Most of these binaries were bound tightly enough that they survived the second encounter with the other galaxy. This indicates that, they are very bounded to each other. Even with all the disturbance from the other particles. The previously mentioned instability also causes a low chance of forming systems with more then 2 particles.

4 discussion

4.1 Unbound particles

We started with looking at different initial conditions for the two merging galaxies. These gave us the result that head-on mergers have a single escaping star, whereas other tested initial conditions had no escaping star. After that, we created two stable galaxies that encounter each other head-on. Up to this point we have not been able to trace massless particles in this stable system, and increasing the number of particles does unfortunately not increase the sample. We have looked at two different scenario's: a soft merger, and a fast galaxy passing through the other. Looking at the structure over time of the galaxies, we can see that the second scenario is more promising than the first scenario. In the second scenario, around 1.1Gyr, we can see a wide spread in the particles of the galaxy. We expect the largest probability for star ejection at this moment. However, this means that the result from the lower amount of particles, used to investigate the initial conditions, could be wrong since the scenarios for different amount of particles differ. Since we find no massless tracers unbound, we aim for finding binaries in a different area.

4.2 Tidal tail binaries

We have found initial conditions for two different type of galaxy mergers, that both produce a tidal tail in one of the galaxies. The first scenario was a short encounter without merger, and the second scenario had a slow merging galaxy. We have used the particles in these tails to search for binary systems. This was done by looking at the distance between those particles, and investigated systems that showed promise of reoccurring close encounters. These candidates were then manually examined to find a handfull of binaries in the tidal tails of one of the merging galaxies. Most of these binaries had already formed before the tidal tail was formed, which leaves us with 1 binary system in the first scenario, and two binary systems in the second scenario that formed in the tidal tail. Most binaries in the first scenario do not survive the fall back into its host galaxy, whilst more then half of the binaries in the second scenario do survive the fall back into the merger. Thus we can say that the binaries in the second scenario are stronger, but since they have lower masses they get more easily disturbed by other particles.

5 conclusion

Soft merging galaxies, and fast encountering galaxies are not likely to eject enough stars to form a binary system with the current simulations. This unfortunately means that we can not say whether or not binaries can form from a galaxy merger. We can however say that the simulations we ran are not enough for finding a binary system.

The merger themselves however provide a large number of particles to investigate binary behaviour. We specifically looked for binaries in the tidal tails of galaxies that were merging/ had a large encounter. The particles in these tidal tails only make up a very small fraction of the stellar mass, but due to their formation they are easily distinguishable from each other. Their small population also creates an environment with fewer interactions, which therefore might stimulate the formation of binary systems.

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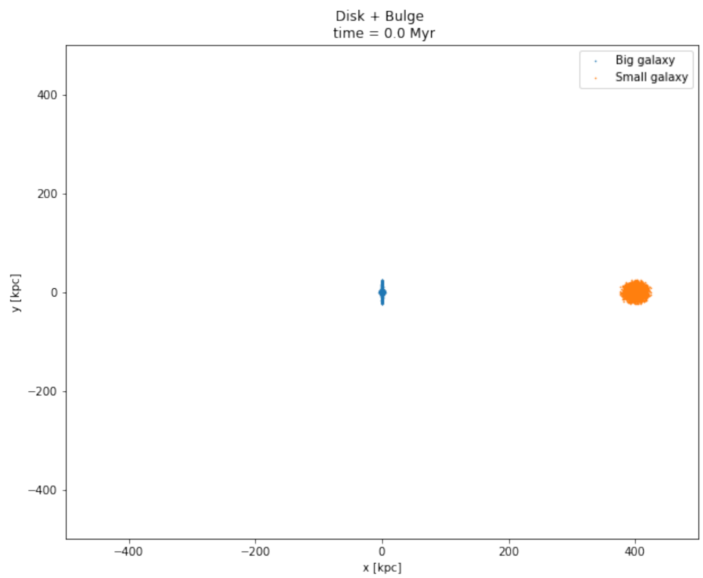
6 Appendix



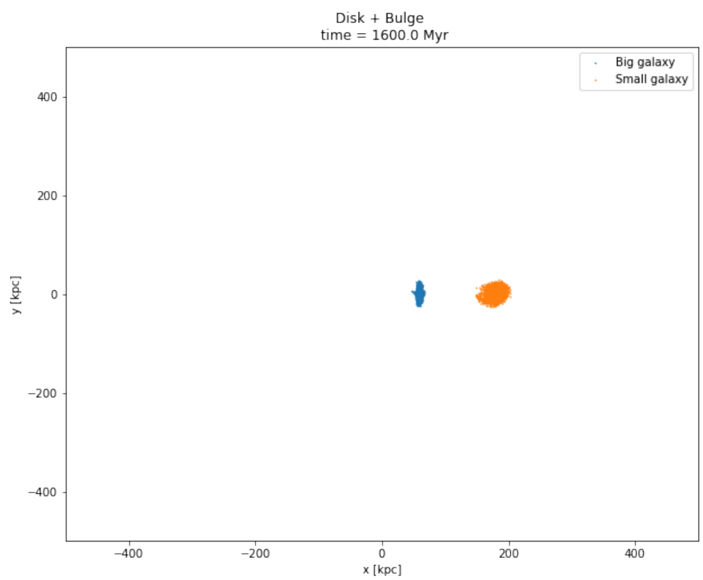
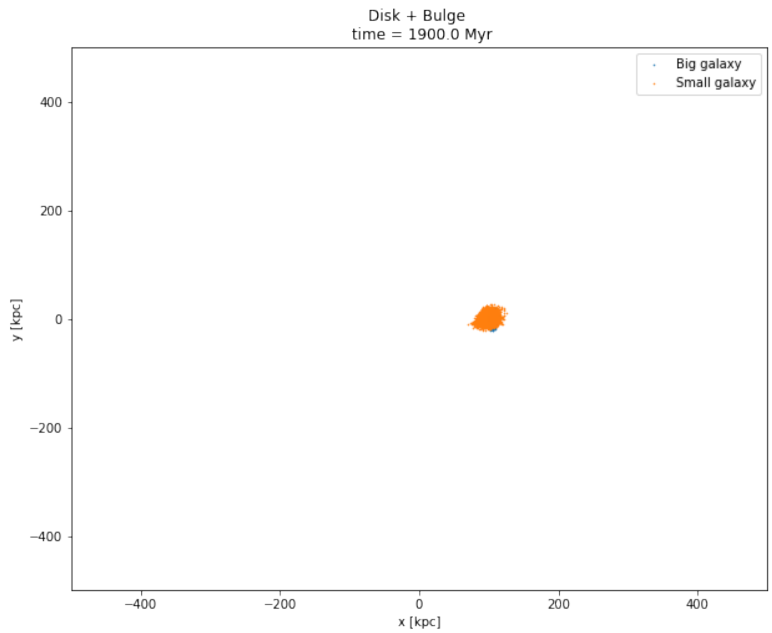


Figure 9: Top: Initial, Bot: Before encounter



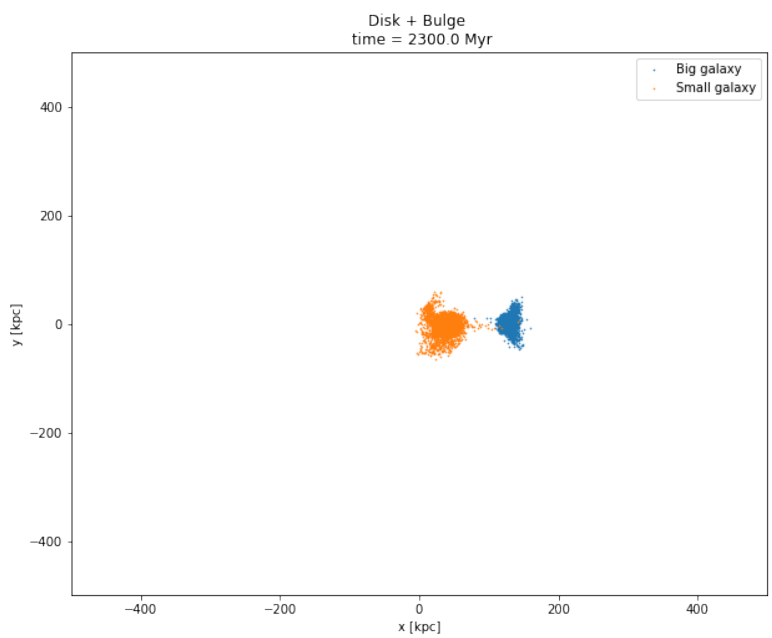
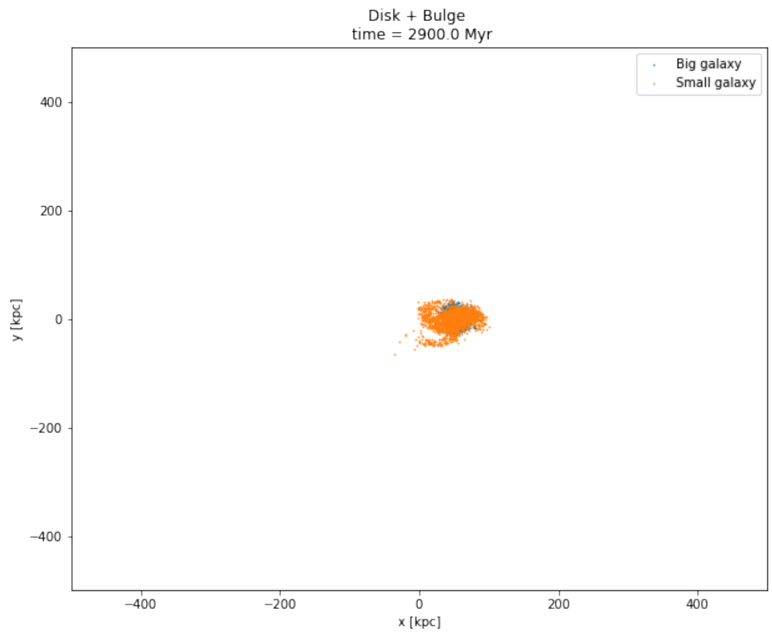


Figure 10: Top: First encounter. Bottom: After first encounter



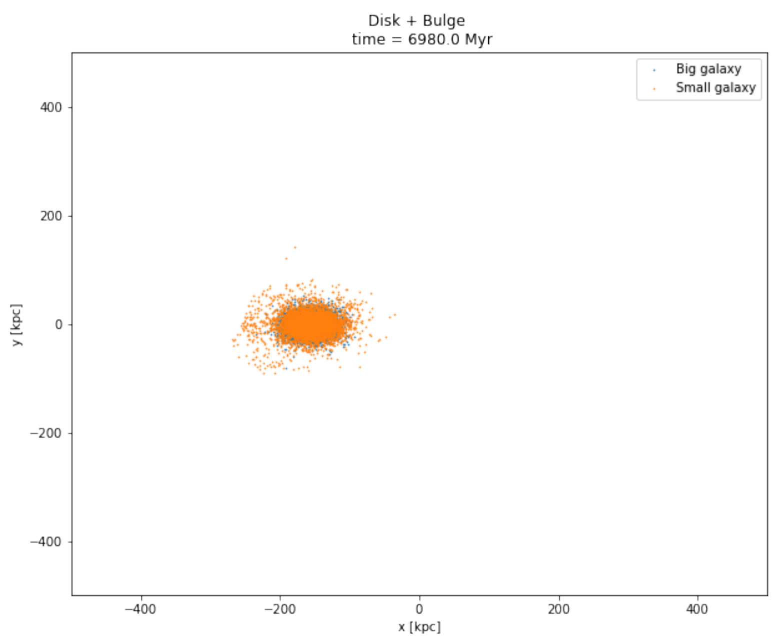


Figure 11: Top: Second encounter. Bottom: End situation

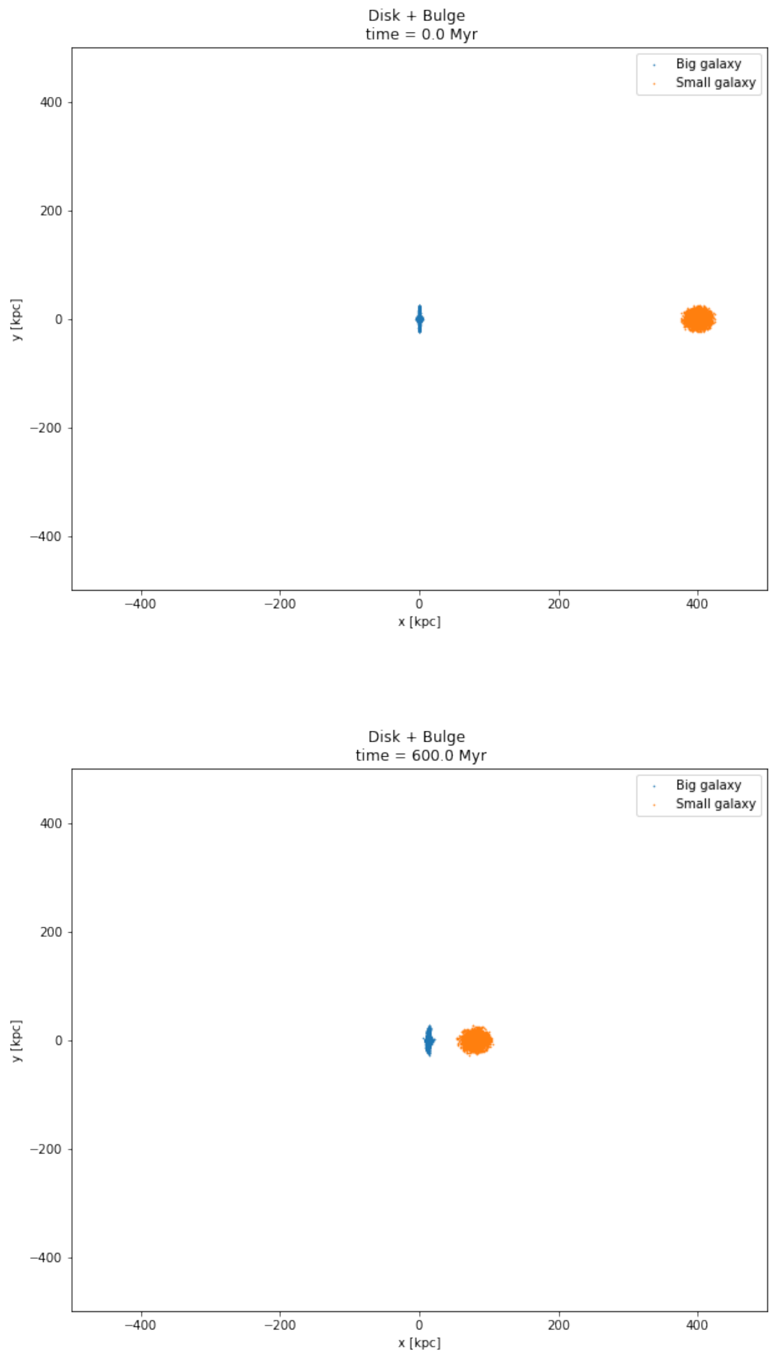
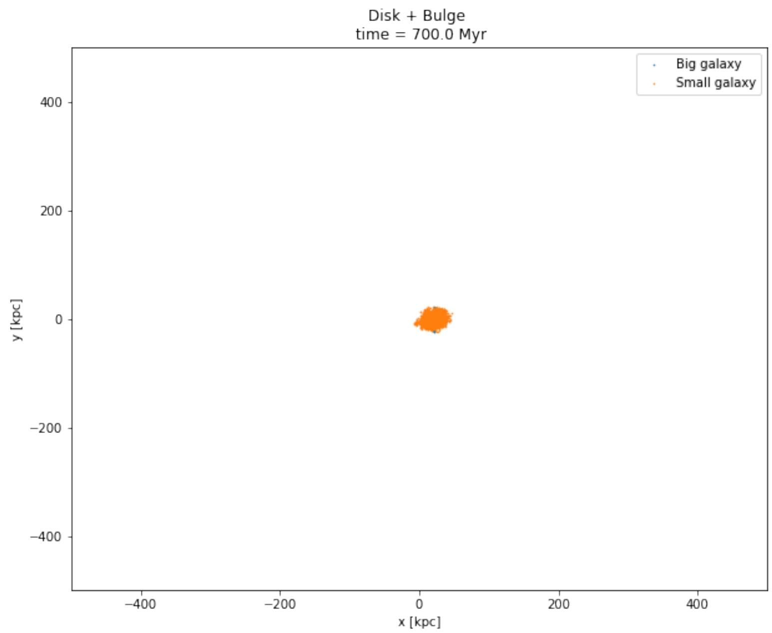


Figure 12: Top: Initial, Bottom: Moment before encounter



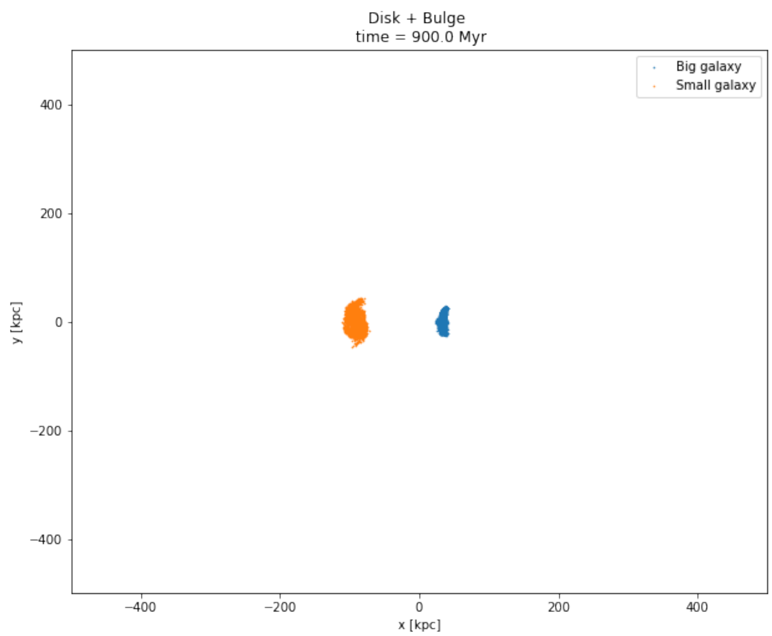


Figure 13: Top: First encounter. Bottom: After first encounter

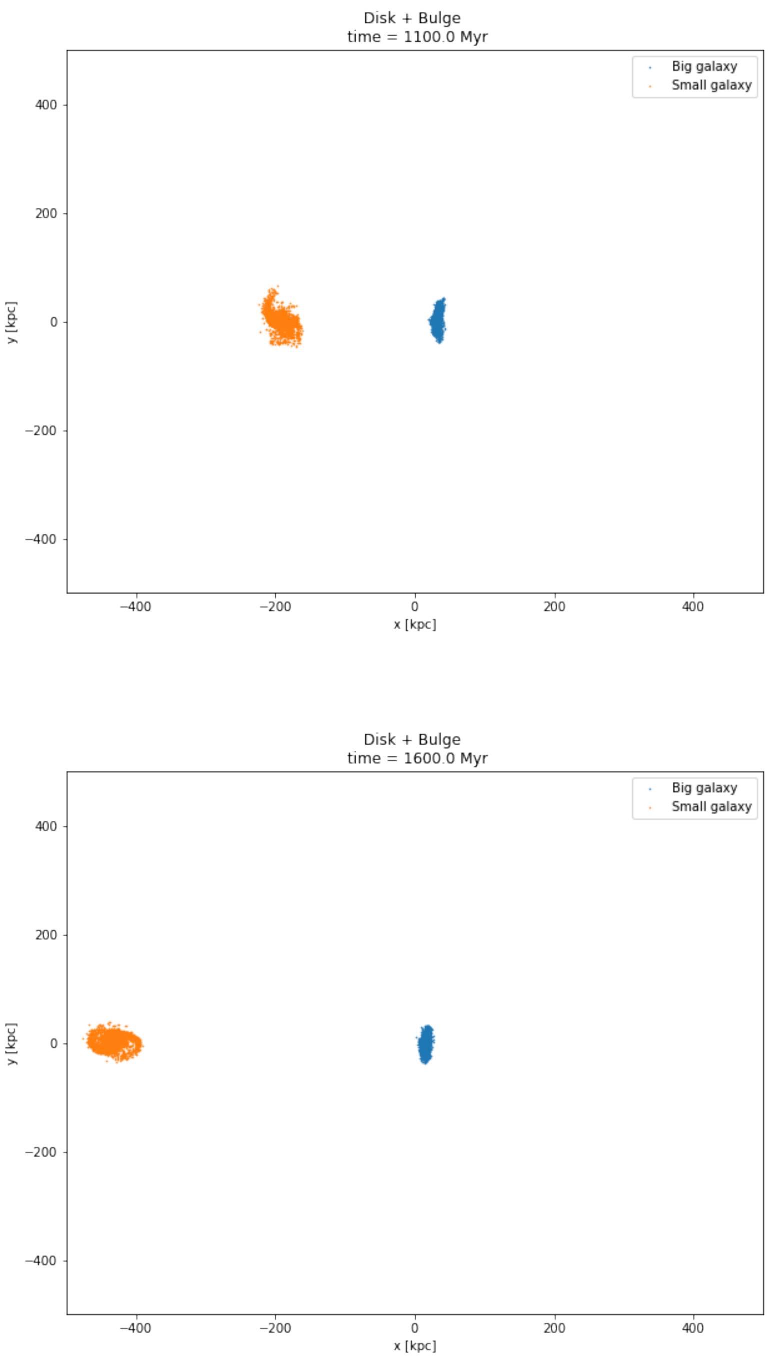


Figure 14: Top: Disruption after encounter. Bottom: stabilized after encounter