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Research Paper

Analysis of Motion of Pairs of Spiral Galaxies around a Black Hole of Comparable Mass

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ABSTRACT: *Knowledge of the motion of galaxies during observation is essential when dealing with distant and complex systems. To provide a better insight to a fairly common situation in our universe, in this paper I present a detailed analysis of a simulation of the motion of two Spiral Galaxies around a Black Hole in an isolated system based on the hypothesis that when galaxy pairs are isolated along a black hole, they will eventually form a hierarchical system of orbits rather than not an orbit at all. I have also provided a numerical presentation of the model with a few assumptions. Two Identical Spiral Galaxies will be taken in a simulation (the application used will be Universe Sandbox 2) along with a super massive Black Hole.*
KEYWORDS: *Black Hole, Spiral Galaxy*

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I. INTRODUCTION

When a galaxy is approached by another celestial object of comparable mass which is not a galaxy, all gas clouds and stars act as if they are orbiting a binary system with the Center Black Hole and other object at the foci of its elliptical path. What is another thing about moving galaxies is that they leave a faint trail which often gives rise to the planet or just consists of rogue planets. Galaxies usually are not found orbiting any other celestial object, rather, they are normally found approaching objects, for example, Andromeda galaxy approaching our Milky Way galaxy. If we talk about simple scenarios, for example, when a Black Hole approaches a galaxy, first of all gas cloud and nebulae in the galaxy start orbiting the approaching black hole. In the moment in time of least separation between the approaching Black Hole and the Center Black Hole, if the Black Holes are close enough, then one would get "slingshotted" by the other one and the galaxy would be decimated with all stars and gas clouds being launched out of orbit into deep space. The path does not change if the lone Black hole, would be replaced by another galaxy because the galaxy moves with the center black hole but this time the gas clouds and the whole star mass would be shot into deep space while some of it remains and starts to orbit one of the two center black holes. It all becomes a lot more unpredictable and chaotic when you take both above stated scenarios together, i.e., when you take two galaxies and one Supermassive Black Hole. The question is whether the galaxies will orbit each other or the Black Hole or not, orbit anything at all and crash into each other due to their gravitational pull.

II. THREE BODY PROBLEM

Initial conditions and coordinate system are as follows:

A Super massive Black Hole(Black Hole #1) of mass 1 Milky Way and Schwarzschild Radius 0.428 light years located at the center of the simulation; A Spiral Galaxy(Spiral Galaxy #1) with mass of 1 milky way and radius 0.637 times that of the milky way whose center is located 200,000 ly away from Black Hole #1 in the positive X direction; A Spiral Galaxy(Spiral Galaxy #2) with mass of 1 milky way and radius 0.637 times that of the milky way whose center is located 200,000 ly away from Black Hole #1 in the negative X direction. Spiral Galaxy #1 and Spiral Galaxy #2 have been given a velocity of 600 km/s in the positive Y direction. The system has been placed in an isolated environment without any effect of other celestial bodies of the universe. Also star formation in the galaxies will be stopped as it might interfere with the motion of the galaxies and might even effect other bodies in the simulation.

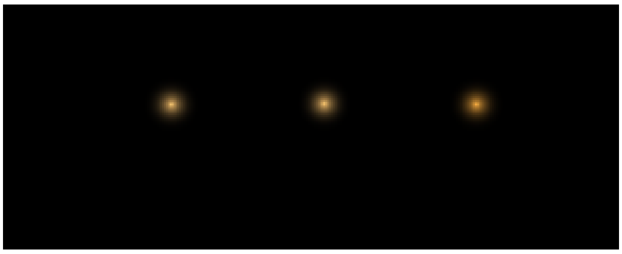

Figure (I). Initial settings for the three-body problem. The distance of galaxies is ‘d’ from the origin and they are given a velocity of 600km/s in the +Y direction. The black hole is at origin.

The three-body problem consists of the elements as displayed in figure (I) with the black hole at the origin, one galaxy at a distance ‘d’ in +X direction and another galaxy at a distance ‘d’ in the –X direction.
Now to begin, let ‘x’ be the distance of the galaxies from the Y axis at any given point of time because the system is symmetrical about the Y axis. I will specify the right to left direction to be of ‘+’ sense and left to right direction to be of ‘-‘ sense.

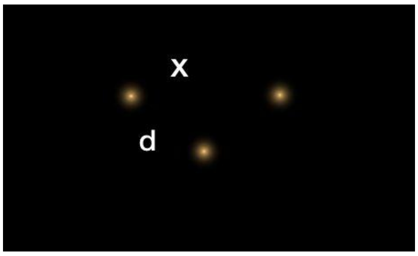

Figure (II). This shows the distance of bodies at some time ‘t’ in terms of x. We can simply apply the Pythagoras theorem, when the distance between Spiral Galaxy #1 and Black Hole #1 is ‘d’.

I will be calculating (a)the time it takes for the galaxies to collide and (b)the distance of the black hole from the galaxy.
Now let’s find the forces on Spiral Galaxy #1,
At T=0, we see the force in X direction as

$$F_x = \frac{GM^2}{4d^2} + \frac{GM^2}{d^2}$$

This force is actually the force at that instant, but to calculate the time taken for the collision, we need the force in the general form. To achieve that, let us look at the time frame at some arbitrary T=t before collision.
Now that we know the setting and movement of the bodies, we can determine the force on Spiral Galaxy #1 in terms of ‘x’ and ‘d’,

$$F_x = \frac{GM^2}{4x^2} + \frac{GM^2 x}{d^3}$$

From here, the acceleration comes out to be

$$a_x = \frac{GM}{2x^2} + \frac{GMx}{d^3}$$

Here, the reason of multiplying the first component by 2 is that the Spiral Galaxy #2 is approaching at 2 times the acceleration of Spiral Galaxy #1, so the rate of decrease in ‘x’ is halved.
Let’s solve this problem using Newtonian Mechanics. To do that, let Spiral Galaxy #1 travel a very small distance in the +X direction and in that time the instantaneous acceleration can be modeled by the equation given above,

$$\frac{dv_x}{dt} = a_x$$

$$dv_x.\frac{dx}{dt} = a_x.dx$$

$$v_x.dv_x = a_x.dx$$

$$\int_0^v v_x.dv_x = \int_d^x \left(\frac{GM}{2x^2} + \frac{GMx}{d^3}\right).dx$$

$$v_x = \sqrt{\frac{GM(x^3 - d^3)}{d^3 x}}$$

We now have the velocity of Spiral Galaxy #1 in terms of its distance from Y-axis and because the system is symmetrical, both galaxies will reach Y-axis at the same time and collide.

$$\frac{dx}{dt} = v_x$$

$$dt = \frac{dx}{v_x}$$

$$\int_0^T dt = \int_d^0 \sqrt{\frac{d^3 x}{GM(x^3 - d^3)}}.dx$$

From here we get an approximate value of ‘T’(time of collision) as follows,

$$T \approx 83.6 \times 10^6 \ years$$

Predicted Result

Using the derived equations, the simulation can bear the following results, for approximately 400 million years, galaxies would move in the direction of their respective velocities and then collide tangentially. Meanwhile, the Supermassive Black Hole would move along the direction due to the gravitational pull and then start travelling in the direction without interacting with any of the galaxies.

III. THE SIMULATION

The motion of galaxies is way more complex than the motion of other rigid celestial bodies because a galaxy is composed of majorly gases and nebulae. Motion of other rigid bodies is well understood and predictable, but the motion of galaxies is way more chaotic and dependant on the initial conditions. To determine the motion of galaxies, first we have to determine the mass and orientation of the nebulae and gas clouds(which in this case is done in the simulation). Then determine the motion of stars and consider their orbital speeds(which here are taken to be negligible). When a galaxy is moving, it is considerate of the motion of its constituents like stars and nebulae stated above, but what could be considered as the Center Of Mass is the Center Black Hole which is generally a super massive Black Hole. We cannot consider the galaxy as a point object and consider other problems, so we will use a simulation in the application “Universe Sandbox 2”.

Each stage of the simulation has been documented as follows:

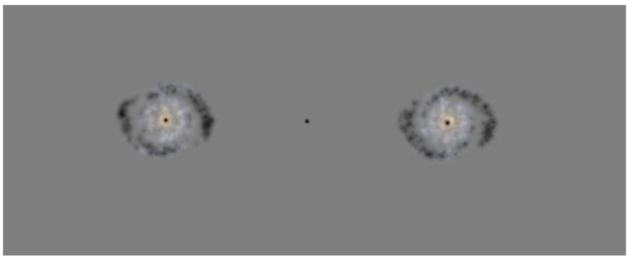

Figure (III). Initial positions of the galaxy pairs and the black hole.

When the simulation starts, the galaxies do not seem to move towards each other, rather continue to move in the positive Y direction. In about 40 million years we can see the galaxy is coming closer together and the effect of the gravitational forces to pull themselves together.

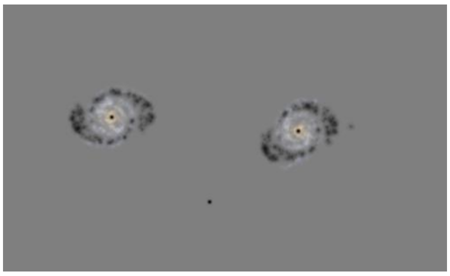

Figure (IV). T= 40 million years.

At t=76 million years we can see the galaxy is touching together and about to collide. Currently we can see black hole number 1 to move from the centre point towards the spiral galaxies.

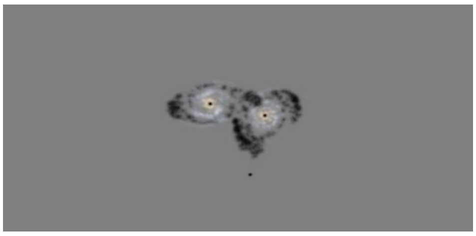

Figure (V). T= 76 million years.

First "Slingshot" of Black Holes.

At t=85 million years we see that the galaxies are midst collision. Moreover during this time the center Black Holes are going through a 'slingshot' interaction where one Black Hole due to the gravitational forces of both, gains enormous speeds while orbiting the other Black Hole and swings out of orbit due to its speed which in the end leaves both Black Holes going at very high velocities in the respective directions. After the collision of the galaxies, no gas clouds are left intact and the effect of the collision can be seen perfectly where the original shape of both galaxies is non-existent.

Effects on Galaxies after first Interaction.

At this time(t=100 million years), the gas clouds are spread throughout space. After the first slingshot happens, we can see that the two central Black Holes are now moving away from each other.

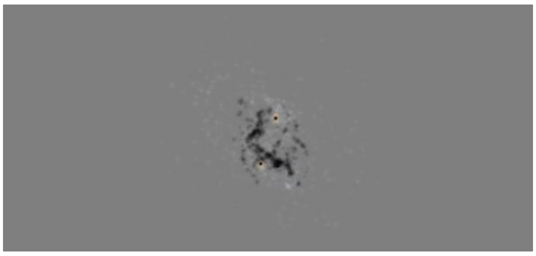

Figure (VI). T= 111 million years. Aftermath of the collision.

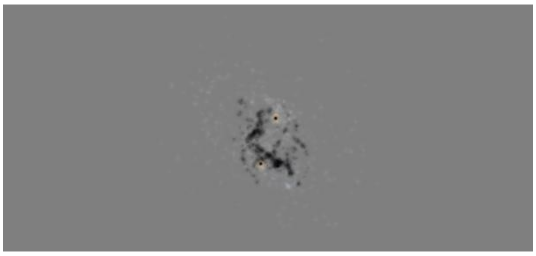

Figure (VII). T= 240 million years. The 'slingshot' interaction.

At this point of time the Black Hole #1 is now coming closer and closer to the Center Black Hole of the galaxy and about to make a flyby.

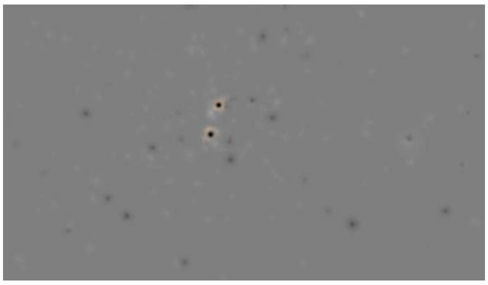

Figure (VIII). T=314 million years. Black Hole #1 reverses its Velocity.

Further on, in the simulation, Black Hole #1 flies by the debris/nebula and the Centre Black Hole. However, the thing to notice here is that the Black Hole when flying by the Center Black Hole does not have much velocity in the expected direction which eventually leads it to come back and start a hierarchal system with the centre Black Holes of galaxies in the binary system and Black Hole #1 as the outside member also orbiting both the Black Holes.

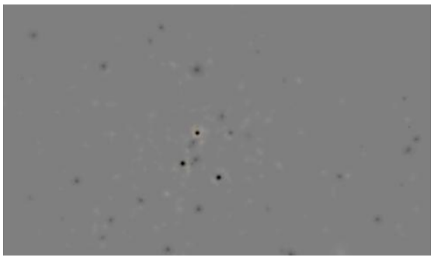

Figure (IX). T=330 million years. The second slingshot interaction

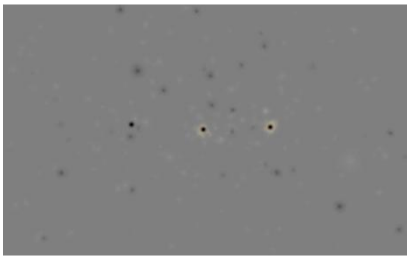

Figure (X). Start of the double binary system.

IV. CONCLUSION

After the running of the simulation and detailed analysis of it, we can deduce that in an isolated system of Two Spiral Galaxies and a Super Massive Black Hole with before stated conditions, the most interesting outcome was the returning motion of Black Hole #1. The "returning motion" could not be accounted for because the only objects under observation were the galaxies. It very well could have been due to the fact that the system was isolated but very unlikely. All in all simulation came out with interesting results with as interesting experiment to run and the hypothesis was correct.