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# A3_3 Power Radiated from Merging Galaxies due to Gravitational Waves

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**Abstract**

In this paper we calculate the power radiated due to gravitational waves during the merger of the Milky Way and Andromeda galaxies. We find that the total power radiated is due to the collision of the super-massive black holes in the centres of the galaxies. We used the masses of the black holes to calculate the initial power radiated and then used the Schwarzschild radius to work out the point of merger. From this we integrated between initial and final positions to find the total power radiated which is equal to 4.97$\times10^{59}$W.

## Introduction

Gravitational waves are fluctuations of spatial strain in the curvature of space-time. They radiate from all objects that have mass and accelerate through space-time, propagating at the speed of light. A common source of gravitational waves is radiation from binary objects which cause energy loss of the system leading towards orbital decay and eventually a merger [1].

In this paper we consider the Milky Way-Andromeda collision and calculate the power radiated due to the merger of the central super-massive black holes. The current distance between the Milky Way and Andromeda is approximately 2.5 million light years and current estimates suggest that the merger will take place in approximately 4 billion years [2].

## Theory

Orbiting bodies radiate gravitational waves due to their acceleration through space-time. The gravitational wave power emitted by an orbiting body is given by Equation 1 [3].

$$P = \frac{-32}{5}\frac{G^4}{c^5}\frac{(m_1 m_2)^2(m_1+m_2)}{r^5} \tag{1}$$

Where $P$ is the power radiated, $G$ is the gravitational constant, $c$ is the speed of light, $m_1$ is the mass of the first object, $m_2$ is the mass of the second object and $r$ is the separation between the two objects.

Although both the Milky Way and Andromeda contain many stars, the chance of the stars colliding with each other upon the merger is negligible due to the vast distances between them. For example, the distance between the Sun and its nearest neighbour is approximately 4.3 light years or $3\times10^7$ solar diameters away [4]. The concentration of stars is greater near the centre of each galaxy, however it is much greater than a solar diameter and therefore, unlikely the stars will collide [5]. Therefore, the collision that takes place will be a collision of the two super-massive black holes at the centre of each galaxy. Once these black holes get within a light year of each other, their gravitational attraction will cause them to orbit each other and form a super-massive black hole binary [6].

## Calculation

The mass of the Milky Way's central black hole has been calculated from studies of the orbits of nearby stars. These studies have led to an estimate of approximately $4.1\times10^6 M_\odot$ [7]. The mass of the Andromeda's central super-massive black hole is not known exactly, however, studies of the orbits of stars have led to estimations of approximately $1.7\times10^8 M_\odot$. The distance at which the two super-massive black holes begin to orbit each other is 1 light year and so we substitute this and the masses of the black holes into Equation 1 giving an initial power radiated of $1.82\times10^{27}$W. This radiated power will lead to energy loss and orbital decay. As the power radiated increases rapidly with decreasing distance, the power radiated vastly increases during the orbital decay until the merger of the two black holes. We shall take the merging distance to be the distance at which the event horizons of the two super-massive black holes coincide. The distance of the event horizon can be found using the Schwarzschild radius, given below [9].

$$R_s = \frac{2GM}{c^2} \tag{2}$$

Where $R_s$ is the Schwarzschild radius, $G$ is the gravitational constant, $M$ is the mass of the black hole and $c$ is the speed of light. Calculating this for the Milky Way's central black hole and Andromeda's central black hole gives $1.21\times10^{10}$m and $5.01\times10^{11}$m respectively. Therefore, the distance between the black holes at the point of merging is the sum of these at $5.13\times10^{11}$m.

The total power radiated in gravitational waves during the in-spiral of the black holes can be found by integrating Equation 1 with respect to distance from the initial orbit position to the final merger position. This is shown formally in Equation 3.

$$\int_{5.13\times10^{11}}^{9.46\times10^{15}} \frac{-32}{5}\frac{G^4}{c^5}\frac{(m_1m_2)^2(m_1+m_2)}{r^5}dr \tag{3}$$

Evaluating this, we find that the total power radiated over the course of the merger is $4.97\times10^{59}$W.

## Conclusion

In this paper, we have considered the collision of the Milky Way and Andromeda galaxies and calculated the total power radiated due to the merger of the super-massive black holes. We assumed that the stars in the galaxis would not collide and the gravitational waves from binary star systems were negligible against those from the black holes. Further work could be done calculating the time for the binary black holes to decay and merge. From this, the energy radiated away during the merger and the mass of the final black hole could be calculated.

## References

[1] https://goo.gl/edvXZs accessed on 25th October

[2] https://goo.gl/SMGy8 accessed on 25th October

[3] https://goo.gl/dBp6fu page 19, accessed on 25th October

[4] https://goo.gl/2O6qJL accessed on 7th November

[5] https://goo.gl/Clxqm line 18, accessed on 25th October

[6] https://goo.gl/G9Ig6t page 5, accessed on 7th November

[7] https://goo.gl/Emv2bj accessed on 25th October

[8] https://goo.gl/DsEFP3 accessed on 25th October

[9] https://goo.gl/gk5Nv8 accessed on 7th November