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A2_5 Black hole Sun

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Abstract

This paper investigates what would happen if a planet's host star was instantaneously replaced by a black hole of equal radius. It was found that the mass of a black hole needed to ensure near enough instantaneous absorption of the original host star is $2.3{\times}10^8$ $M_\odot$. Latterly some other consequences of the new Black hole Sun have also been explored, like using the Roche limit to calculate the effect of tidal forces.

Introduction

In the film "Star Trek" [1] a star predicted to be going supernova soon was thought to be, in classic SciFi terms, a threat to the galaxy. In particular this explosion was a threat to the nearby planet Romulus. The intended solution was to use "red matter" [2] to create a black hole that would absorb the explosion and thus save both Romulus and the galaxy. However in this scenario we are imagining that the near supernova star is the Romulan Sun. This paper will be addressing how massive a black hole would need to be such that it would completely absorb the star, therefore preventing it from going supernova and destroying Romulus.

Assumptions

Due to lack of information we have chosen to model the red supergiant on the star Betelgeuse and the planet Romulus on the Earth. We are able to assume a black hole that is neither rotating nor charged as it has been created by fictitious "red matter" and simply placed into being. Therefore the only defining property it has is its mass, which makes it a Schwarzchild black hole. This allowed us to use its Schwarzchild radius as the event horizon, the radius within which not even light can escape. As we are making the black hole massive enough to absorb the entire star we will assume that the Schwarzchild radius matches the radius of the star and that the red matter is able to appear at the centre of the star.

Equations and results

Taking the radius of Betelgeuse to be 955 $R_\odot$ [3], G as gravitational constant and c as the speed of light. Using the equation for Schwarzchild radius r_s (1)

$$r_s = \frac{2GM}{c^2}, \tag{1}$$

we calculate the mass limit of the black hole to be $M = 2.3 \times 10^8$ $M_\odot$. These results are within the mass limits of a supermassive black hole. However given this increase in mass we are now presented with a new problem as we cannot expect the planet nor its orbit to stay the same.

Firstly a habitable zone for Romulus was calculated using Betelgeuse's original parameters. Using a habitable zone calculator [5][6][7] which takes into account the star's effective temperature and luminosity, in this case 3590 K [3] and 90,000-150,000 $L_\odot$ [4] respectively. We used the 'inner habitable zone' result at both luminosities as that was the result with a stellar flux closest to that of our Sun. For this we used the Roche limit (2), which calculates the distance at which a smaller celestial body, held together by its own gravity, will be destroyed by the tidal forces of a larger celestial body.

$$d_R = R_m \left(2\frac{M_M}{M_m}\right)^{\frac{1}{3}}, \tag{2}$$

where the d_R is the Roche limit, R_m is the radius of the smaller body, in this case Romulus, M_M is the mass of the larger body, in this case the black hole and M_m is the mass of the smaller body. However as inertia force and rigid structure are ignored in this equation the results are approximate. Assuming that Romulus would be $4.5 - 7.5 \times 10^{10}$ km away from Betelgeuse, as given by the habitable zone calculator, at $d_R = 3.4 \times 10^8$ km it can be assumed that Romulus would be safe from tidal destruction as it would be orbiting at $\sim 130 - 220$ times d_R. However, regarding the orbit of Romulus, given the sudden increase in mass the orbit would certainly be disrupted.

Discussion and Conclusion

Despite this information it seems very likely that Romulus would be pulled towards the black hole and be unable to avoid crossing the event horizon, due to the sudden increase in mass of the central body. Also even though we have calculated that Romulus would not be entirely destroyed by its tidal forces, we have not calculated how tidal forces would affect the planet and if so, how much disruption they would cause. However if there were a situation in which this could be prevented then the planet might be able to survive if the accretion disk of the black hole was able to provide enough light and heat to maintain it. In the event of survival life on Romulus would be very different as, due to the time dilatation caused by the black hole, contact with the rest of the galaxy would be difficult to maintain and would isolate them from the rest of the known galaxy.

The black hole mass calculated here, $M = 2.3 \times 10^8$ $M_\odot$, is an upper limit as black holes are able to absorb objects with radii larger than their own and so the minimum mass would be a suitable subject of further investigation.

References

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