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P5_2 Spaghettification: Surviving a Black Hole Event Horizon

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Abstract

We found that it is possible to stay conscious while falling across the event horizon of a black hole if the mass exceeds $\approx 19,000$ M$_{sol}$. This assumes the average person is of good health and can stay conscious with a relative force less than $5\ g$ acting upon them.

Introduction

Black holes are among the most mysterious objects in the universe, appearing to devour both matter and light, and allowing neither to escape its enormous gravity. They have a number of features unique to the extreme environments they create, such as the infinitely dense singularity theorised to be in the centre of the black hole, and the event horizon, the boundary at which radiation and matter cannot leave or be observed from outside the black hole.

In this article we explore the possibility of survival for a human passing through the event horizon of various mass black holes. We consider the relative g-forces that may act upon the person for a given range of black hole masses, and find whether this reaches a lethal level. Other physical phenomena which may make such a journey dangerous are not considered in depth in this paper, as such we are assuming the person appears instantly at the event horizon and thus ignoring special and general relativity. For simplicity the body of the person falls feet first perpendicular to the event horizon, where 'inside the event horizon' is the point at which the person's head has just passed through the event horizon.

Excessive and sustained g-forces can drain blood away from the brain causing cerebral hypoxia, leading to a loss of consciousness. This is known as g-force induced loss of consciousness or G-LOC [1]. The g thresholds at which this occurs depends on an individual's fitness, training and age, but a figure of $5\ g$ is reasonable [2].

Theory

The acceleration (g) due to gravity is given by Equation (1) [3].

$$g = \frac{GM}{r^2} \qquad (1)$$

Where G is the gravitational constant and is equal to 6.67×10^{-11} m^{3}kg^{-1}s^{-2}, and M is the mass of the object, in this case the black hole. This is used along side Equation (2), the Schwarzschild radius [4] r_s - the radius of the black hole's event horizon, which also uses $c = 3 \times 10^8$ ms^{-1}, the speed of light - to find expressions (Equations

(3) & (4)) to express the gravitational acceleration at the head and feet of a person of height H, where we use a height of 1.65 m.

$$r_s = \frac{2GM}{c^2} \quad (2)$$

Equations (3) and (4) express the gravitational acceleration at the top of the person's head at height H and at the bottom of their feet, respectively, falling past the event horizon.

$$g_{head} = \frac{GM}{r_s^2} \quad (3)$$

$$g_{feet} = \frac{GM}{(r_s - H)^2} \quad (4)$$

Due to the extreme gravitational gradient between the head and the feet, the body would experience severe tidal forces (Equation (5)) causing the phenomenon termed spaghettification, where the body would be severely stretched.

$$\Delta g = |g_{head} - g_{feet}| \quad (5)$$

Results

As the mathematics to find a suitable black hole mass via analytical methods becomes complex, we employed a graphical method to find the relevant masses by inputting varying masses into Equations (3), (4) and (5) and plotting the Δg, as shown in Figure 1.

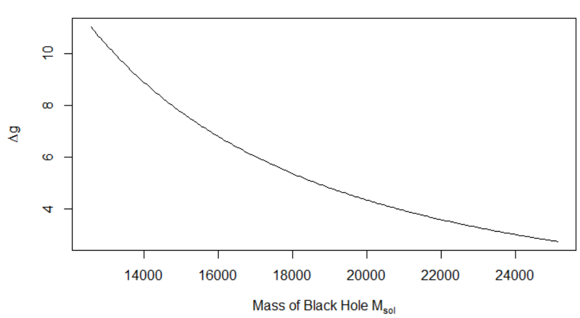

Figure 1: This graph shows the range of black hole masses which would produce tidal forces under the g-force limits typical to a human.

From this graph, it is clear that a falling person would still be conscious whilst passing through the event horizon of a black hole with a mass greater than $\approx 19,000$ M_{sol}, assuming that the average person can withstand less than 5 g.

Conclusion

The findings suggest that the larger the black hole the greater the liklihood of making it past the event horizon in good health, when only considering the gravitational effects of a black hole; the force gradient on the infalling human body is more gradual the more massive the black hole is. As mentioned previously, a black hole of mass greater than $\approx 19,000$ M_{sol} produces tidal forces not lethal to an average healthy human who is expected to survive less than 5 g of force. Many people are capable of surviving forces greater than 5 g, such as fighter pilots and astronauts, but to do so have extensive training and equipment to help avoid G-LOC. By contrast, the extreme gravitational gradient of a small black hole would be lethal to the human body, and the aforementioned spaghettification will occur.

Though in theory the g-forces experienced as one falls through the event horizon of a massive black hole are gentle enough to survive for a short period, current models of black holes would suggest that survival is ultimately futile as one approaches the infinitely dense singularity in the centre. Other risks of such an extreme environment must also be considered, such as high radiation emissions or other infalling matter which would likely pose a serious risk. As such, the authors recommend future astronauts take precautions to avoid falling into black holes.

References

[1] https://goo.gl/s3Y4GX (12/10/16)

[2] https://goo.gl/5xvrIv (13/10/16)

[3] https://goo.gl/WidP0B (13/10/16)

[4] Carroll, B, W. and Ostlie, D, A. (2007) *An Introduction to Modern Astrophysics* Second Edition. San Francisco: Pearson. p. 635