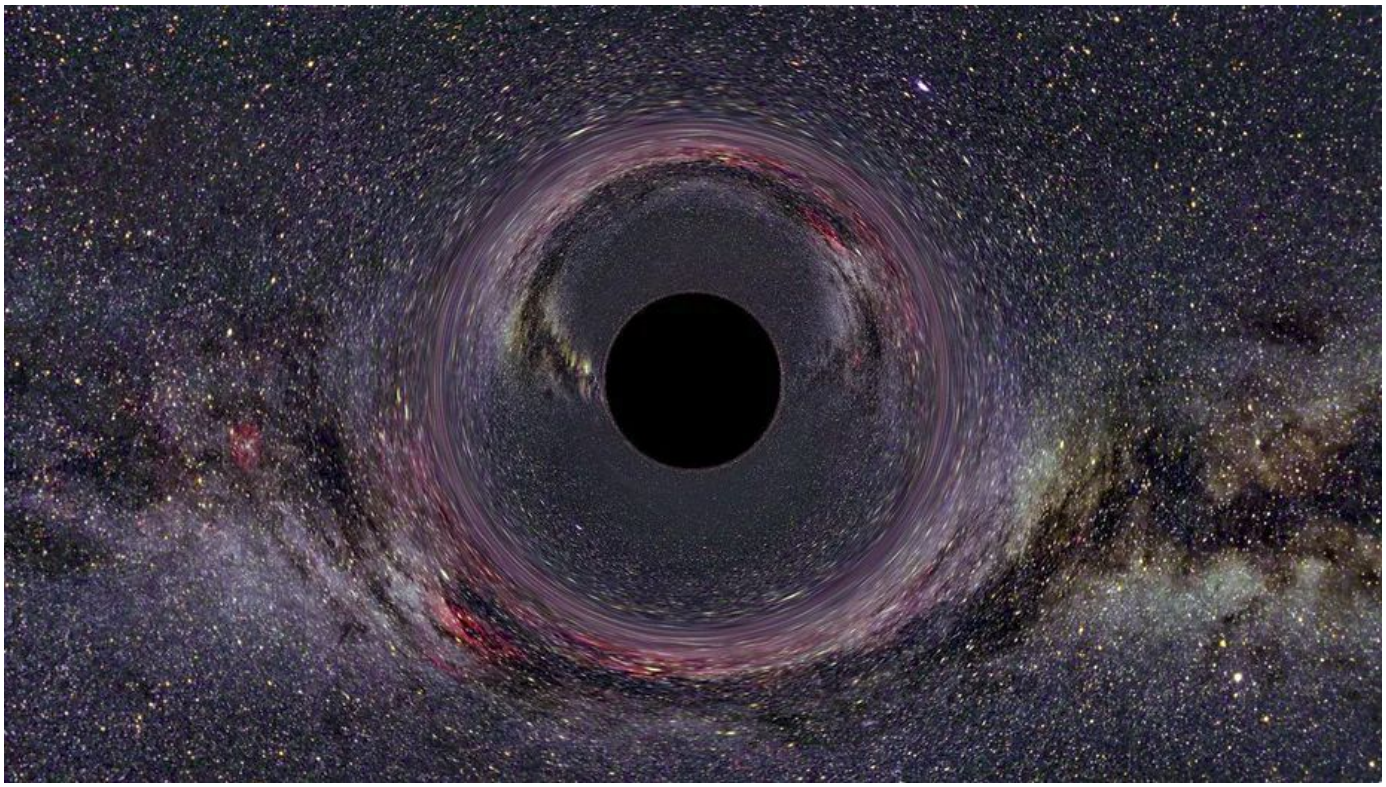
# Is it really impossible to move through the Black hole??



## A big big thank you!

**With tons of motivation and pleasure, we feel very delighted to present our detailed report on a very interesting yet perplexing misconception about one of the most bizarre phenomena in the entire cosmos, Black Holes. Before we plunge into our documentation, it's worth being grateful to our instructor in this project, Dr. Reetanjali ma'am for assisting us in various phases of this presentation and providing us some useful reading materials related to space prodigies. At the same time, we would also like to thank our physical chemistry instructor Dr. Manikandan Paranjothy sir for arming us with some basic still very useful concepts and hypotheses of Quantum Mechanics which we have used frequently to unclog the presented misconception.**

# Contents

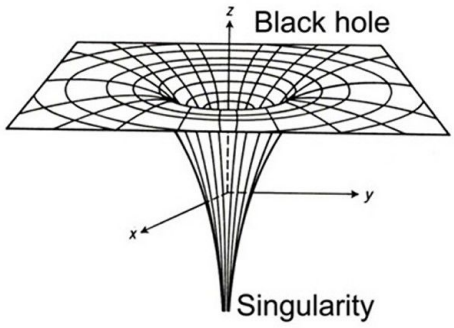
# 1. Some basic terms regarding blackholes

Before diving into the theories, misconceptions and its evidence part, it is necessary that we should have a note on some of the key terms related to black holes that we should be using throughout our demonstration.

## 1. Event Horizon

In simple words, as a particle moves closer and closer to a black hole, it starts experiencing a tremendous amount of gravitational pull due to the collapse of heavy objects such as stars into a very small area. Event Horizon is a point in black hole where the escape velocity needed to cross it exceeds the speed of light since gravitational pull tends to infinity there. According to Einstein's Theory of Special Relativity, nothing can travel faster through space than the speed of light. This means a black hole's event horizon is essentially the point from which nothing can return. The name refers to the impossibility of witnessing any event taking place inside that border, the horizon beyond which one cannot see.

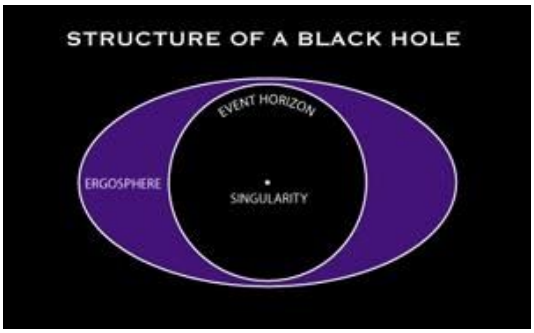
## 2. Singularity




Singularity is a one-dimensional point containing a huge mass in an infinitely small space, an outlandish spot where density and gravity become infinite and space-time curves infinitely, and where the laws of physics as we know them cease to operate.

According to the "cosmic censorship" hypothesis, a black hole's singularity remains hidden behind its event horizon, in that it is always surrounded by an area which does not allow light to escape, and therefore cannot be directly observed.

## 3. The Schwarzschild Radius



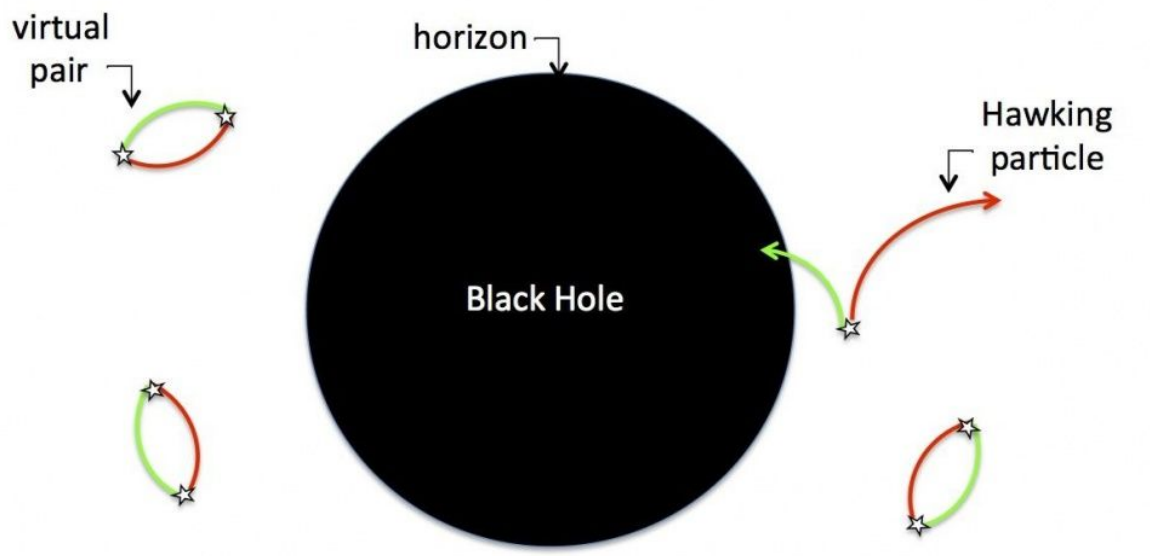

This term denotes Event Horizon's radius. It is the radius at which the escape velocity is equal to the speed of light.

To find the Schwarzschild radius one simply uses the speed of light as the escape velocity . By setting $v_{escape}$ equal to the speed of light c, then:

$$v_{escape} = (2GM/R)^{(1/2)}$$
$$c = (2GM/R)^{(1/2)}$$
$$c^2 = 2GM/R$$
$$\text{and } R = 2GM/c^2.$$

So, once an object, even a beam of light, is closer to the black hole than a radius of $2GM/c^2$ then there is no escaping the black hole's gravitational pull.

## 4. Hawking Radiation




Also known as "Black hole Evaporation", Hawking radiation is more likely a theoretical assumption which predicts the emission of black body radiation due to some quantum effects near the event horizon of the black hole. This radiation does not come directly inside the black hole but rather are mainly caused by quantum fluctuations which create 'virtual particles or Hawking's particles' and come into existence by Black hole's gravitational force. As the

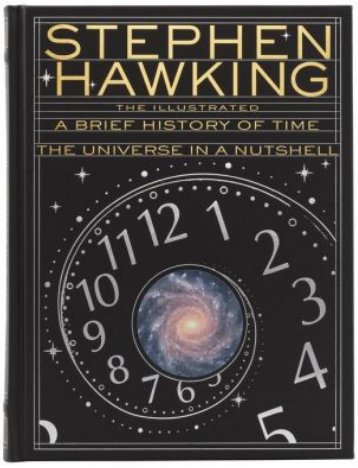
particle–antiparticle pair was produced by the black hole's gravitational energy, the escape of one of the particles lowers the mass of the black hole. Because of this, black holes that do not gain mass through other means are expected to shrink and ultimately vanish. As the radiation temperature is inversely proportional to the black hole's mass, micro black holes are predicted to be larger emitters of radiation than more massive black holes and should thus shrink and dissipate faster.

# 2. A brief overview about the fallacy

So the main question we'll be trying to bring up is "Is it really impossible to cross a Black hole?" and this is a point where a series of misconceptions starts in the minds of almost every astronomy enthusiast and here we'll be presenting an outlook why this misconception exists and why even we consider it a misconception. (The things we'll be discussing in this section, proof of these is mentioned in further upcoming sections.)

To cross the black hole, a particle will need to pass the Event Horizon, about which we have discussed in the previous section. It is a place where if a particle needs to go beyond it, it'll require a velocity even greater than the speed of light and achieving it is impossible according to Einstein's theory of relativity. It in simpler words says that the length of moving objects shrink in the direction in which they move with very high velocities. Get to the speed of light (not really possible, but imagine if you could for a moment) and the object's length would shrink to zero. So even particles as small as electrons can't pass through it. Though there are theories about hypothetical particles like Tachyon which is believed that if existed It could travel with a speed greater than light. But still it's imaginary which clearly emphasises it's impossible to pass through a black hole at any condition provided, which is openly penned in some of the famous articles and books whose reference we'll be attaching further.

# 3. Popular theories supporting the Hypothesis

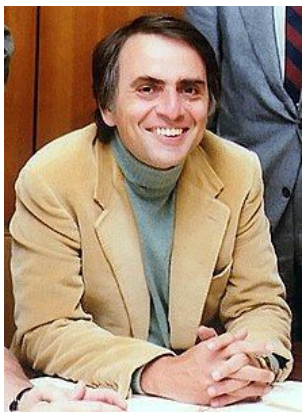



1. Hawking, Stephen. 'The Illustrated Brief History of Time' Published by Bantam in 1996.

In chapter 6 named 'Black holes' (page no 104) of this book, Stephen Hawking portraying the infinite gravity evidently mentioned that classical mechanics axioms aren't sufficient to wind up that escaping the black hole is possible. But at the same time, he wrote "Black holes exert such an incredibly powerful gravitational force that even a photon, which travels at speed of light, could not escape." Though his ideology was quite straightforward and apparent, at one point he seemed firmed about the impossibility of going through it and at other he presented his hypothesis of 'Hawking's Radiation' where he insisted the phenomenon of negative energy which an anti-particle due to some quantum

fluctuations attains and get swallowed by it. This theory in some aspects appears a bit vague keeping in mind the current scenario in the field of Quantum Mechanics.

2. NOVA Physics + Math. "Carl Sagan Ponders Time Travel." NOVA. Oct. 12, 1999. (July 20, 2011)



Carl Sagan, an American astronomer, planetary scientist, cosmologist, astrophysicist, astrobiologist, author, and science communicator, in his conference talking about time travel supported Einstein's special theory of relativity that no material object can travel as fast as light. It is forbidden. There is a commandment: “Thou shalt not travel at the speed of light, and there's nothing we can do to travel that fast.”

And if nothing can travel faster than that, according to these discussions, this explanation too suggested that it is quite impossible to cross the Event Horizon of the black hole.

3. Kevin Boyce and Koji Mukai. "Light and the Blackholes." NASA's Imagine the Universe: Ask An Astrophysicist. Feb 28, 2003


In NASA's initiative "Ask an Astrophysicist" , answering about the possibility of escaping it , even they denied that prospect writing "In a Black Hole, light traveling outwards towards an event horizon is pulled back by the very strong gravitational field, because of the warping of space-time inside the event horizon, regardless of the lack of a photon mass. This prevents light or any particle from ever escaping the Black Hole at any circumstances".

**In the presented articles, if we summarize the zest in all, they with the reference of "Einstein's Theory of Relativity", denied every possibility of crossing it.**

**And now, we'll try to unscramble this misconception using some of the phenomena explained in Quantum Mechanics and try to clarify its proof as well. Though the upcoming anomaly shall appear true in special scenarios only but clearly refuses the impossibility as highlighted earlier.**

# 4. Unfolding this misconception and its proof

In 1905, German Physicist ‘Albert Einstein’ came up with his theory of wave-particle duality (in light) and in 1922, Compton Effect verified its correctness. But according to the findings, that theory of ‘duality’ was only confined to the Electromagnetic Waves and pulses. It was in 1924 when a French Physicist Louis de Broglie proposed that every single particle in the cosmos, if it has acquired a finite velocity behaves as a wave as well and defined the basic features of it like wavelength and frequency by rendering a relation between particle velocity and wavelength ( $\lambda$ =h/mv) that signified that electrons or photons which move with a very high speed possess wavelike nature too.

In the emerging field of Quantum Mechanics, we know that it is possible to locate an electron in different scenarios using the Schrodinger Equation. Though its usage can be generalized for non-electronic particles as well, we'll for now take the reference of an electron for simplicity. So, by knowing the potential energy of an electron, we can substitute it into the Schrodinger equation and hence obtain its wave function which defines a settled path on which it is supposed to move.

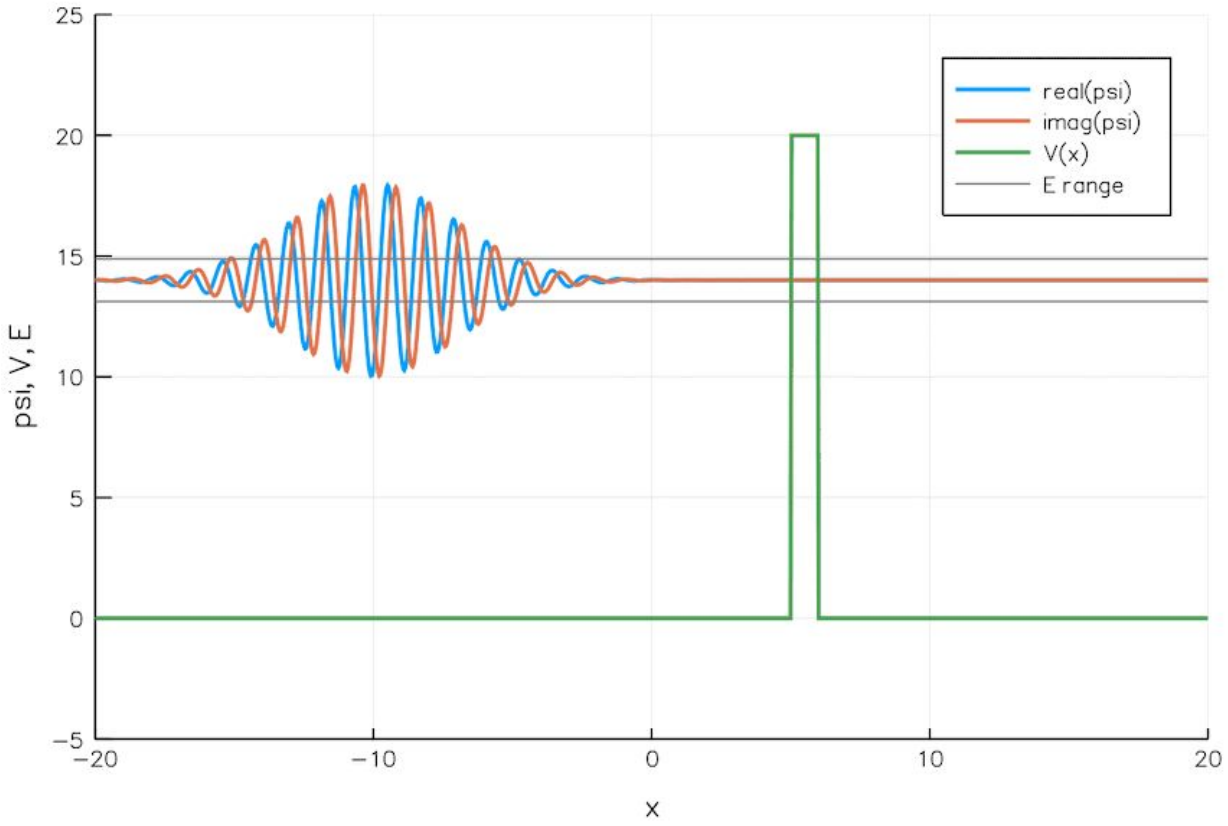
But actually the bizarre fact is that particles don’t always tend to follow that predefined path derived and that outlandish

phenomenon is popularly known as **Quantum Tunneling,** which is the base of our explanation about a way of crossing a balck hole escaping that infinite gravity at the Event Horizon.

- **What is Quantum Tunneling and how this could be applied in case of Black holes??**

-> Classical Mechanics states that every particle due to virtue of its position maintains a finite Potential Energy. It's not a property of a particle but depends on the environment the entity is placed. As in the Schrodinger equation, when we substitute the expression of V(x)(potential energy), the wave function that comes out is imprisoned by that potential barrier. For example, In Particle in a 1-D box problem, for $x<0$ and $x>l$ (l is the length of the box, x is position), the wave function is bounded and classically it is not possible to move out of this barrier.

**Tunneling** is a phenomenon or a process in which a quantum mechanical particle exists in a classical forbidden region without any probability current(flow) appearing inside the barrier. The reason why it is happening is often explained by the Heisenberg uncertainty principle discussing the uncertainty in the exact location of these particles allowing them to move in space moving outside the potential barrier too.




(GIF source : wikipedia)

As in the animation above, we can observe that the potential barrier(the green spike at x approximately equal to 5) has its energy equal to 20 (in respective units) and with the mean wave packet with energy approx to 14, some portion of it is able to cross that.

## Mathematical proof in brief

For explanation to be simpler, we'll be using the time-dependent Schrodinger equation for a particle moving in 1D (for 2D or 3D, spherical coordinate system is widely used).

$$-\frac{\hbar^2}{2m}\frac{d^2}{dx^2}\Psi(x) + V(x)\Psi(x) = E\Psi(x)$$ (Schrodinger eqn)

Adjusting some of the terms and coefficients, it can be written as,

$$\frac{d^2}{dx^2}\Psi(x) = \frac{2m}{\hbar^2}M(x)\Psi(x) = \kappa^2\Psi(x), \qquad \text{where} \quad \kappa^2 = \frac{2m}{\hbar^2}M.$$

And M(x) is (V(x)-E) and it can be +ve or -ve.

Using WKB approximation, the whole expression can be expressed as

$$\Psi(x) = e^{\Phi(x)} \text{ where } \Phi''(x) + \Phi'(x)^2 = \frac{2m}{\hbar^2}\left(V(x) - E\right).$$

This is a ordinary differential equation of order 2, so using power series method **about x1 (the point at which particle is supposed to turn or the potential barrier point),**

The entire expression comes out to be,

$$\frac{2m}{\hbar^2}\left(V(x) - E\right) = v_1(x - x_1) + v_2(x - x_1)^2 + \cdots$$

Since it's a 1D problem, so to keep expression linear, we'll ignore the quadratic terms in the equation written above.

The LHS side can be substituted in original Schrodinger eqn and hence we'll be getting a differential eqn,

$$\frac{d^2}{dx^2}\Psi(x) = v_1(x - x_1)\Psi(x)$$ whose solution can be found using ODE concepts and by analyzing reflection coefficients and transmission

coefficients, the global solution of a particle tunneling through a single potential barrier can be found as,

$$T(E) = e^{-2\int_{x_1}^{x_2} \mathrm{d}x \sqrt{\frac{2m}{\hbar^2}[V(x)-E]}}.$$

# Now the foremost question here is, how practical is it and how will it allow an entity to pass the infinite gravity and in which special conditions??

(So, arriving at the last part of our presentation, we'll be trying to cover all these scruples at our best.)

Till now what we have learnt is that the potential barriers encourage these particles to confine themselves in a specified area but every once in a while a subatomic particle manages to pass through it and in our point of view even Black Holes are not immune to it.

In a documentary named "**Black Holes, the Other Side of Infinity**"(funded by NOVA, the National Center for Supercomputing Applications, NASA and the National Science Foundation) in 2006 by Andrew Hamilton, a little hint was shared about the possibility that the phenomena "Hawking's Radiation" could be caused maybe due to the subatomic particles escaping through it as there's almost negligible possibility that a radiation could pass through it and to explain that break out, tunneling process was taken into the account too.

Similar to the Tunneling, that a particle randomly unfollows the predefined path crossing the barrier, sometimes there is an arbitrary change in the amount of energy in a specific point of space as well

which is basically known as **Quantum Fluctuations**. It was first observed in the vacuum that there were random fluctuations in the values of electric and magnetic fields present in it. After that with more experiments (eg- The Casimir Effect in 1997 ), the Quantum realm defined 'An Empty Space' as an area which roils with quantum particles flitting in and out of existence. In short it presented that **Virtual Particles** are the cause of those fluctuations which are created in particle-antiparticle pairs. As they are created spontaneously without any source of energy, they don't follow Energy Conservation Laws and annihilate in a specified time.

Coming to our exploration about the way to escape, Quantum Mechanically there is a possibility to leave behind the tremendous gravitational pull, a possibility to tunnel out. But for this to happen it'll need some notable conditions which we guess it's a right time to unveil.

**For a particle to escape a black hole, a quantum fluctuation must occur at a black hole's edge and why we are being so specific because when it happens, there will be a huge possibility that one particle (from particle-antiparticle formation as discussed above) will tunnel out before the annihilation takes place. For this prodigious separation to happen, there should be some delay in the annihilation time and for this delay, the particles produced should possess very very high wavelengths. As we know that every entity possesses a wavelength which is inversely proportional to its velocity, so for wavelength to be much higher, its velocity near the horizon should be very low. To be more precise, wavelengths which are comparable to the size of black hole will be able to tunnel out.**

**We can actually compare the Event Horizon's radius or 'The Schwarzschild Radius' (derived earlier) with the wavelength of a particle moving with a velocity v ($\lambda$ =h/mv), we'll find that velocity is inversely proportional to the square of mass (this is just an approximation for a rough idea) which we think is a vague idea about the velocity at which the particle is supposed to move. These huge wavelengths allow one of the ghostlike to roam in the domains extending beyond the Black holes.**

As it may be surmised that the explained analogy is very rare to happen, but we are certain that if actually 'Hawking's Radiation' exists (proof of which is available) in the cosmos, then this phenomena is conclusive to take place with it too. Though with present technology and advanced equipments, these radiations are not observed as the darkest one among the black holes are one billion-trillion-trillionth as bright as a 100-watt light bulb which is beyond the focal length of the lenses used, but that doesn't mean it's impossible to happen.

So Yes, we believe that the impossibility for an entity to cross a balck hole is a misconception and with that the impossibility to escape infinite gravity is a misconception as well.

Thank you.

*"Look up at the stars and not down at your feet. Try to make sense of what you see, and wonder about what makes the universe exist. Be curious."*

-Stephen Hawking