# An Overview on Black Holes

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**Abstract—** For this paper, I want to talk about the lifecycle of a black hole and the physics behind it! Some of the things I will be talking about include how they form, what happens after you get pulled in, and what Hawking radiation is. This paper is like a crash course on everything you would need to know to be able to read and understand any new piece of information we have on them!

## I. INTRODUCTION

Have you ever looked up at the night sky, wondering what holds our galaxy together? The Milky Way is a vast collection of stars, dust, dark matter, and other solar systems but what prevents it from flying away? We believe that a supermassive black hole at the center of the Milky Way is a key player in all this. But to understand how this works, we must learn a few key concepts!

The first thing we must understand about black holes is how they form. A black hole is formed when a massive star's hydrogen (fuel) runs out, making it collapse inwards with great force! Whereas for stars not as big, they would collapse inward into roughly the size of a white dwarf but do not judge a book by its cover as the gravitational force is also almost as strong as a black hole! Now that we know how a black hole forms, what happens to us when we get pulled in? There are 2 main theories that we have currently, spaghettification and the firewall. Spaghettification happens when you cross the event horizon of a black hole! Where your body vertically gets elongated and horizontally gets compressed. The next theory is the firewall, as a black hole consumes so much matter it would have high amounts of energy! Through the immense power of that energy, the human body would just burn to a crisp.

## II. THEORY

A cosmic phenomenon that has one of the most powerful gravitational pulls in the universe, warping space-time itself. A black hole is so densely packed together that not even light can escape! They are created when giant stars collapse! Up next we have what types of stars can turn into a black hole and how [2].

The three-star types that can become black holes are Main Sequence Stars, Giant Stars, and Supergiant Stars. Main Sequence stars make up 90% of all star populations! Our star starts its life off in the molecular clouds which are often 10 - 1000 solar masses. These molecular clouds are pretty cold which results in clumps of gas, creating high-density pockets of gas! When I say clumps, it looks more or less like a cloud than a solid object! When the clumps collide with each other, it increases their gravitational attraction and mass. Sadly, gravity causes our clumps to collapse inward to form a ball, where due to friction and gravitational energy, our ball heats up! This heating up causes our ball to emit radiation, which in the beginning just escapes to space. However, as the mass of our protostar continues to grow due to gravity, the radiation gets trapped! This causes our protostar to heat up even more. While heating, if our star can reach ~10 million degrees kelvin we get a star that uses nuclear fusion to heat itself! Nuclear fusion is very useful, as it produces energy for the star to fight against gravity. This is what our protostar was doing earlier; creating inward pressure to fight the pressure of gravity. If our star can continue its nuclear fusion process, it can be defined as a Main Sequence star. Our star lives its longest during these stages, continuously changing and lasting for millions or billions of years. Now that we have a pretty good understanding of the life of main sequence stars, let's talk about their types!

* Spectral M-type is a star that has a solar mass of 0.2
* Spectral K-type has a solar mass of 0.7

These are stars that are less than the mass of the sun. The K-type stars often range from colors of orange - yellow and are called orange dwarfs. The M-type stars are often in the color red and are called red dwarfs. Next, we have stars that are greater than or equal to the Sun's solar mass but aren't big enough to be a black hole!

* Spectral G-type is a star with a solar mass of 1
* Spectral F-type are stars with solar masses of 1.5
* Spectral A-type with a solar mass of 2

As you can see, the G-type star is one with a solar mass of 1! This means that our star is a G-type which is a yellow dwarf and is often in the color of yellow. The F-type star is greater than the sun and ranges from the color of yellow, white, or somewhere in between those 2. Lastly, A-type stars have colors that are either white or cyan! Next, we have stars that can turn into a black hole.

* Spectral B-type is 10 times the size of the sun
* Spectral O-type is 40 times the size of the sun

These are the stars that are able to become black holes! But how? Well, for this we must come back to nuclear fusion. Remember how in the Main Sequence stage of our star, we had nuclear fusion to keep the star from collapsing? Well, at one point our star will start to lose its "fuel" and because of this, the gravitational push on our star is too much for it.

This results in the helium turning into carbon (which makes the core turn into a carbon one) which in return helps maintain the balance between gravity and nuclear fusion. This is when our star starts to turn into a red giant. The next core to balance everything out is oxygen, and here are the rest (this list is when a star will become a black hole) neon, magnesium, silicon, and iron. Now, back to our red giant. A red giant forms when the gravitational force causes the core to collapse. When our core collapses, an increase in heat arises! As a result, the outer layers expand. Once our star loses all of its fuel, it immediately collapses. As our core collapses under its own gravity, the outer layers shoot outwards! But you might ask, why does the core collapse inwards but the layers go outwards? Well, this is because of the law of "For every action, there's an equally opposite reaction". Resulting in our fascinating black hole! Now that we know how, what are the parts of the black hole? [14][15][16][17]

A black hole consists of many parts, even though in reality it consists of 2. The event horizon is classified as the boundary of no return. You can take this as falling into an endless hole where now, there is no way for you to come back. Now what's after getting pulled in from the boundary of no return? Well, thanks to the potent gravity the black hole has, you will experience such great forces it will spaghettify (although we will discuss other theories soon). The singularity point is where all the gravity is so intense that space-time curves infinitely! Although, we can't say for sure if the singularity really exists as it's in the center of the event horizon, which is beyond our limit of sight. The accretion disk is the flow of gas, plasma, dust, or particles around any astronomical body (but for us, it's a black hole). The matter that orbits the accretion slowly loses its energy and starts to spiral toward the black hole. What is the accretion disk for? Well, you can take it as the fuel tank for the black hole (although, black holes don't need to consume mass to live) that helps the black hole grow! When an astronomical object gets too -close to a black hole, the black hole starts to rip apart this object. The matter is now one with the black hole where because of the intense spinning (and gravitational energy) the matter heats up really fast! The event horizon shadow is formed because of the distortion of space-time and gravitational lensing. This is because as the event horizon captures light, the light gets redirected from the above two reasons. The photon ring(s) is a reflection of the accretion disk; it's also visible on every side of the black hole! Here, this light orbits the black hole a couple of times before coming to us. Doppler beaming is when we see that one side of the accretion disk is red and the other is blue. This effect was visible when we took the first picture of a black hole! When the light travels toward us, it appears to be compressed. However, when it appears to not be traveling to us, it gets stretched out giving us a red color. The corona is like a violent storm, just maybe a million times greater. This is because the corona is controlled by a magnetic field while being ~ billion degrees hot. If a particle even enters the corona it will approach speeds close to light. Where did this magical magnetic field come from? Well, the accretion disk! The accretion disk must've collected it from stars, neutron stars, etc. Lastly, the particle jet. The particle jet is a jet stream of particles that move at close to the speed of light! Supermassive black holes can have a particle jet that spans hundreds of thousands of light years! Sadly, we don't currently know how they work. Next, we will discuss what black holes look like! [2][3][6][7]

A black hole is essentially invisible! However, there are methods useful to find them! There are 2 ways to do this, the first is gravity! The black hole warps space-time enough that we're able to use that to our advantage and pinpoint the differences (of objects that are getting gravitational lensed). How do objects appear warped if the object is close to the black hole? Well, light travels in the fabric of space-time! But a black hole curves that space-time by a lot! This results in the light taking an immensely curved path, where when it arrives to us looks like the galaxies have been squashed (or thrown off to wholly another location. The other method is when an object gets consumed. This helped us find the very first image of a black hole! How does it help? As our matter gets consumed, it gets pulled apart which causes an accretion disk to form! This very accretion disk emits radiation and light! Which gives us access to look at the black hole [2].

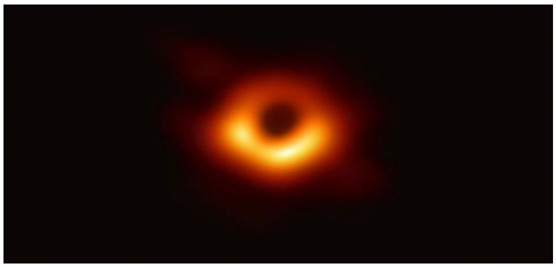

Fig 1: The First Black

John Mitchell was the person who coined the idea of black holes; he wondered if there were objects in space that had enough gravitational force to trap light! The first people to really discover a black hole were Paul Murdin and Louise Webster who had found the Cygnus X-1(a stellar black hole) in 1971. John Michell had a Master of Arts degree and a bachelor of divinity. He spent his entire life working for a church, he was also a geologist who'd made a great impact in the seismology section. John Michell was an amateur when it came to astrology, but was an avid telescope builder! At one point in his astronomical career, he had written a letter to John Cavendish in 1783 (the year black holes were coined) about the idea of an object whose light would get trapped. Paul Murdin is a British astronomer who led the Anglo-Dutch Isaac Newton Group of telescopes. Where he did his research on supernovae, black holes, and neutron stars. He was also the science administrator for the British government and the Royal Astrometrical Society. Louise Webster was also an astronomer who did significant research in the fields of planetary nebulae & x-ray binaries. With her colleague Paul Murdin, they found the first clear black hole candidate Cygnus X-1. [10][11][12]

A black hole has won the title of having the greatest gravitational pull! But exactly how does it work? When stars form and reach their iron cores, they collapse under their own gravity (going supernova) turning into a black hole. Since the star collapsed, our hopeless star core continues to collapse into itself. Resulting in a core or singularity that's infinitely dense, because our core can't fight back nuclear fusion. To understand how a black hole affects time, we must go over a couple of things. Let's suppose we have a graph representing time on the y-axis and distance on the x-axis. We can just lay this graph out, this is the representation of space-time. If we put a mass on this sheet, we can say that it curves the fabric causing time dilation. When space-time fabric is curved, the time axis gets bent and elongates. Now, note that I only said TIME AXIS the DISTANCE AXIS's value never gets changed. Lastly, why is there an event horizon? A black hole has an event horizon because it marks that boundary of no return! This means that any light that passes through can never come back. Thus making a dark region (that sort of covers the singularity!).[17]

Professor Stephen Hawking's most famous theory is Hawking Radiation! Imagine this, what if we have 2 opposite particles that cancel each other out? Now what would happen if we put those 2 particles near a black hole? 1 particle goes into the black hole whereas the other can either go into the black hole or escape (causing evaporation). That's Hawking Radiation in the basics for you! But now, wouldn't it seem like the black hole is growing rather than losing mass? Yes, but thanks to the first law of thermodynamics, the law of conservation of energy which tells us that energy can't be created or destroyed and only be converted! This means there was a conversion between mass and energy. To explain this, remember that one formula, E = MC^2, this very formula talks about the relationship between energy and mass! This means that energy can turn into mass and vice-versa. Therefore proving the existence of Hawking Radiation![23][24]

Nothing can escape a black hole because of its immense gravitational pull. This is because you would have to be at the speed of light or greater to escape it. However, as soon as something passes the event horizon, it can never come back. It is permanently lost. This is what Stephen Hawking had found out given the knowledge of general relativity and the structure of a black hole. Hawking radiation can not transport any information, which creates a dilemma between general relativity and quantum mechanics.

## III. DO BLACK HOLES HAVE A MINIMUM/MAXIMUM SIZE?

Currently, there's no set-in-stone value for the minimum size of a black hole. Where people argue that a black hole can be any size! However, some people believe they do have a minimum value (either the size of an atom, nucleus, or even smaller). In that case, we could also say that a black hole has no maximum size! But, scientists have seen that in the core of galaxies, the black holes wouldn't exceed 10 billion solar masses. When it comes to size, we may also talk about when they grow fastest! A black hole grows fastest in areas where there's rapid accretion. Say for example, while eating a star, molecular cloud, or even other black holes. As we've discussed above, there's no limit to how big a black hole can be![19][20]

## IV. WHY IS THE STUDY OF BLACK HOLES IMPORTANT FOR UNDERSTANDING THE UNIVERSE?

The study of black holes helped us prove Einstein's theory of general relativity, which links mass, space, and time together in a space-time fabric order. We can take a black hole as a laboratory for testing out how the universe works on the largest and smallest scales. Thanks to black holes, we also know that Einstein's theory of general relativity and quantum mechanics don't work with each other. Gravity doesn't work with quantum mechanics because quantizing gravity proves to show a lot of weird conceptual and mathematical problems. Till now, we haven't found a universally effective way that can link general relativity and quantum mechanics.[2][26]

## V. WHY DO ONLY SOME BLACK HOLES ROTATE?

There can be 2 black holes, the Schwarzschild black hole, and the Kerr black hole! The Schwarzschild is a black hole that is symmetrical, and non-rotating! Schwarzchild came upon this black hole because of the Schwarzschild metric which just says that the path of light changes when there's a nonrotating mass (light's path can also change when the object is spinning). The Schwarzchild looks like any other black hole but without the spin to it. The Kerr black hole is a spinning black hole based on the Kerr metric! The Kerr metric is one answer for Einstein's Field Equation (which is trying to find the space around a rotating black hole). Over here, Kerr had come up with an answer that said that rotating black holes is the answer. Given this, how does it function? A Kerr black hole consists of a singularity, an inner horizon (these we don't see), an outer horizon, an Outer Station Limit Surface, and an ergosphere. We have an inner and outer horizon as the inner horizon is a "leftover" of the math equation (which describes the vacuum around a black hole). The Outer Station Limit Surface is where an effect called "Frame Dragging" occurs. The Outer Station Limit Surface (OSLS if you will) forces everything to follow the rotation of the black hole! This means that even a photon that moves at the speed of light, will have to obey the black hole's rotation! Now, what if our photon was at the surface of the OSLS? What would happen if it went the other way? Well, it's just going to freeze there (in an angular coordinate which means the black hole can move but the photon will stay in the same angle). Frame Dragging states that our reference point would have to follow the point or object for it to look stationary! One last thing about the OSLS, when our black hole starts to rotate faster and faster, the OSLS goes further and further back! Finally, the Ergosphere! The ergosphere is the region between the OSLS and the outer event horizon! More importantly, it's the section where energy can easily escape because it hasn't entered the event horizon! As a result, we can make a black hole lose its rotational energy only if there is some way to extract those particles. The one way you can extract particles is through the Penrose process! The Penrose process states that if a particle gets split by a black hole, where one half goes into the black hole and the other escapes. The escaped particle gains energy because the particle can simply gain energy through the absorption of light! In the future, if we ever get near a black hole we could use the Penrose process to farm energy! Our black hole loses rotational energy in the same way that Hawking Radiation causes mass loss. The law of conservation of energy! This means that the rotational energy had to convert into creating a particle (even if it's half). [21]

## VI. EVENT HORIZON THEORIES:

There are 2 main theories for what happens after the event horizon. Spaghettification and the firewall theory! Spaghettification states that when you enter the event horizon, your matter will be turned into spaghetti that's one atom wide! The firewall theory states that you will burn to a crisp as soon as you cross the event horizon. Spaghettification requires one key thing, gravity. When an object gets through the event horizon, every point of the body feels different gravitational effects. This causes your body to stretch out, as your foot might take different gravitational effects then your head! The firewall theory works because a particle and its antiparticle would split apart at the event horizon. When our particle just bounces off the event horizon, that "explosion" between the two particles causes a little bit of heat to form. As more and more particles come, the event horizon heats up even more! Finally, Spaghettification requires gravity and different effects off it on every body part, whereas the firewall requires a particle and its antiparticle to "explode" at the event horizon generating heat.[27]

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## VII.CONCLUSION

In conclusion, there is still much left to discover about black holes, black holes has really played a key role in helping us confirm very important theories! This entire paper discusses on the different theories associated with black holes and its relevance with physics , this entire paper is a form of literature survey on the same topic.

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