BLACK HOLES

Everything You Need to Know About Black Holes and Black Hole Physics

Black Holes: Everything You Need to Know About Black Holes and Black Hole Physics

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Introduction

I want to thank you and congratulate you for downloading the book, “Black Holes: Everything You Need to Know About black Holes and Black Hole Physics”. Consider this the one-stop-shop on black hole information.

Black Holes have been, and are still to this day, one of the great mysteries of cosmology. They have inspired the imaginations of generations when looking out into space and have been the focus of astronomy for years. Today, much is known about black hole physics and the characteristic of these great beasts of space. This book will bring you up to speed with what we know today about black holes.

Chapter 1 – Black Hole Fundamentals

The Basics

Black holes are regions in space where the gravitational pull is so strong that even light can't escape.

In physics, in order for an object like a rocket to escape the gravitational pull of Earth (or what is known as the escape velocity), it must have a velocity of 11 kilometers per second (km/s). For black holes, the escape velocity is faster than the speed of light, and since nothing on this universe can be faster than light, then nothing escapes a black hole.

The term "black hole" appears to have come from the concept of "black bodies" which are objects that reflect no light.

Black Hole History

1700's

John Michell first presented the concept of a black hole in 1783. Michell supposed that a star would have a force so strong that light would not be able to escape from it.

In his book, *The System of the World*, scientist Marquis de Laplace mentioned such a star. He failed to push through with this concept because his idea ran in conflict with the wave theory of light, which was then the prevailing theory.

1920's

Everything changed when the wave theory of light was challenged by a new theory, Albert Einstein's *General Relativity*. Then, German physicist Karl Schwarzchild conceptualized a structure he called a singularity. He based his assumptions on Einstein's general relativity where he thought in theory of a point of zero volume but with infinitesimal density. Sir Arthur Eddington, however, opposed the concept of this point of infinite density, in 1924.

1930’s

Astrophysicist Subrahmanyan Chandrasekhar put the concept of a white dwarf’s anatomy forward in 1931. This led to the understanding of mass limitations, which decide what becomes of the star when it dies: a white dwarf, a neutron star, or a black hole.

In 1939, Robert Opppenheimer explained the nature of the points of infinite density. He said that objects of extreme density could cause light to deviate and bend towards the star.

1960’s

The years leading to the 1960s ushered in the golden age of general relativity. In 1958, David Finkelstein identified Schwarzchild’s continuity surface as the event horizon.

It took another 30 years before John Wheeler coined the term “black hole” in 1967. It was first used by Ann Ewing in the article “Black Holes in Space” on January 18, 1964, as a report during a meeting by the American Association for the Advancement of Science. At the same time in 1964, Jocelyn Bell-Burnell discovered neutron stars. At that time, the discovered objects were the densest objects found in space through observation.

All the assumptions came to a head when pulsars were discovered in 1967. The pulsars were actually neutron stars rotating at a very high speed. During that time, neutron stars and black holes were just theoretical bodies, but by 1969, everything changed with the discovery of the rapidly rotating neutron star.

1970’s

In 1970, the famed physicist Stephen Hawking formally created much of the theories we currently know about black holes. He also discussed the final destination of the said black holes through the Hawking radiation.

The first suspected black hole was discovered in 1970 and was called Cygnus X-1. Cygnus was said to emit X-rays and is accompanied by an object smaller than planet Earth but with a mass significantly heavier than that of a neutron star.

The launch of the Hubble Space Telescope provided the best evidences so far of the presence of black holes at the center of some galaxies. This was after one of the on-board instruments called the Space Telescope Imaging Spectrograph (STIS) saw the orbiting objects around the center of these galaxies.

Chapter 2 – A Black Hole is Born

Considerable debate has erupted over the years regarding the existence of black holes. For one, the author of general relativity himself, Albert Einstein, was averse to the idea of an object with infinite density, contending that collapsing particles will be able to stabilize themselves at a certain radius.

Over the years, however, some scientists began to rethink the possibility of physical black holes and not just as an unnecessary result of Einstein's *gedankenexperiment* equations. The tide of belief started to turn in the 1960s when scientists were able to prove that the formation of an event horizon is possible. The formation of an event horizon is a precursor of the formation of a black hole.

According to Roger Penrose, once an event horizon forms, a singularity can then form somewhere inside it. A black hole is formed primarily through the process of gravitational collapse. There are also other processes that are involved in the formation.

Initial Stage of Black Hole Formation

1. **Big Bang Explosion**

   Black holes formed during the Big Bang explosion are called primordial black holes. According to the theory, during the early stages after the Big Bang explosion, certain high-density regions were formed allowing for the creation of black holes.

   Over the years, several early models of the universe were drawn up with varying conditions for the formation of black holes. Based on these models, high-density regions alone cannot form black holes but should include other factors such as a disturbance in the density.

2. **Massive Collisions**

   Massive collisions that involve high amounts of energy may also result in black hole formation. Collisions which achieve high density concentrations are more likely to produce black holes.

The high-energy collision formation of black holes, however, has been dismissed by some scientists as purely speculative.

3. **Gravitational Collapse**

The gravitational collapse of an object such as a star can result in a black hole. This happens when the pressure inside the object is insufficient for the object to overcome its own gravity.

Since gravity by nature is weaker, gravitational collapse only happens to massive objects. The most famous of this kind of collapse are dying stars which are running out of fuel to burn. Less fuel means lowered temperature leading to the reduction of internal pressure and the eventual collapse of the star on its own weight.

The result of a gravitational collapse of a star is a compact star. Compact stars can be white dwarfs, neutron stars, or black holes.

Gravitational collapse results in the formation of stellar black holes. According to astrophysicists, the collapse of massive stars after the Big Bang may have resulted in the massive stars found in the centers of most galaxies.

How Did Some Black Holes become so Big?

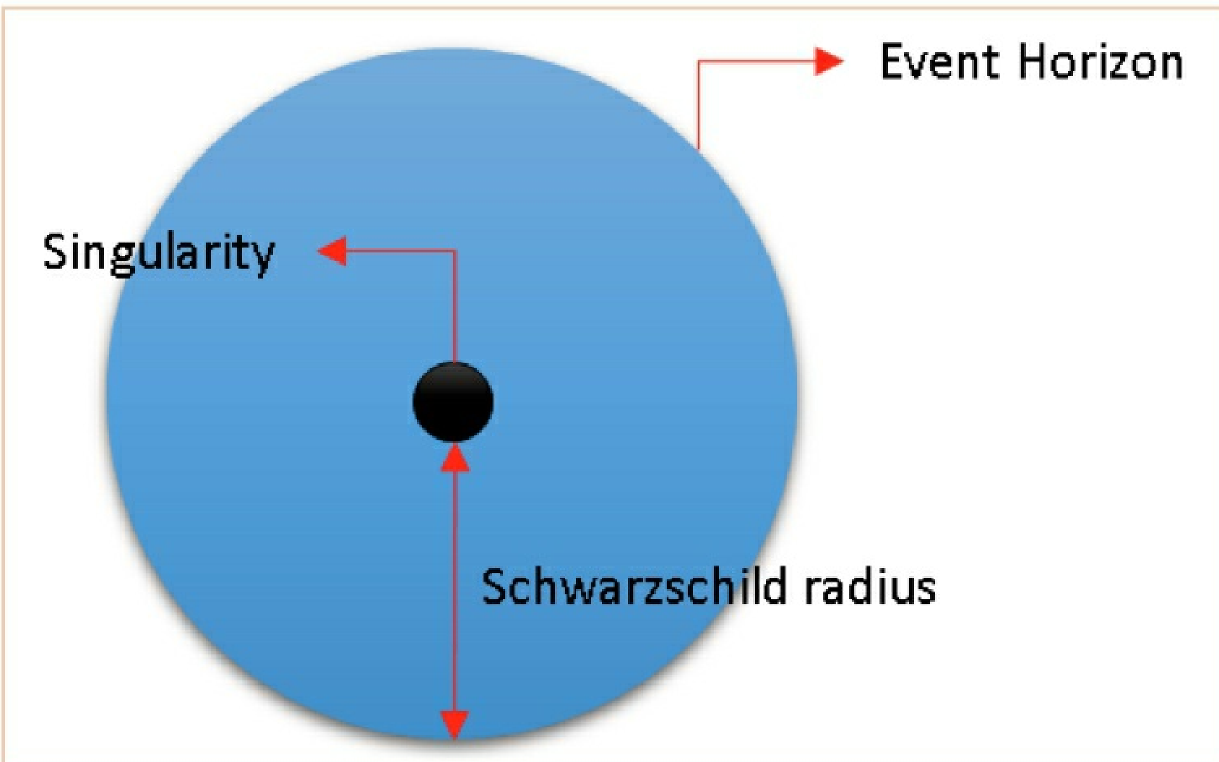
Most black holes today are bigger than when they were formed. This is because a black hole continues to grow by adding more mass that gets caught in its gravitational field. Black holes continue to accumulate dust and other matter in their paths, a process that may have resulted in the massive black holes that have been observed in our own galaxy.

Black holes may also grow by eating other stars or merging with other black holes. The merging of objects may not necessarily result in bigger black holes. However, this process may have helped in the early stages of black hole formation. Intermediate-mass black holes may have resulted from the formation of smaller objects. This process is thought to have been critical during the early stages of the Big Bang when massive black holes were formed.

Chapter 3 – Anatomy: Event Horizon

Anatomy

A simple black hole is composed of three basic parts. The outermost fringe is called the event horizon. The inner form is called Schwarzschild radius where the escape velocity is equal to the speed of light. The nucleus or the center of the black hole is called the singularity where all the laws of physics no longer apply.



Event Horizon

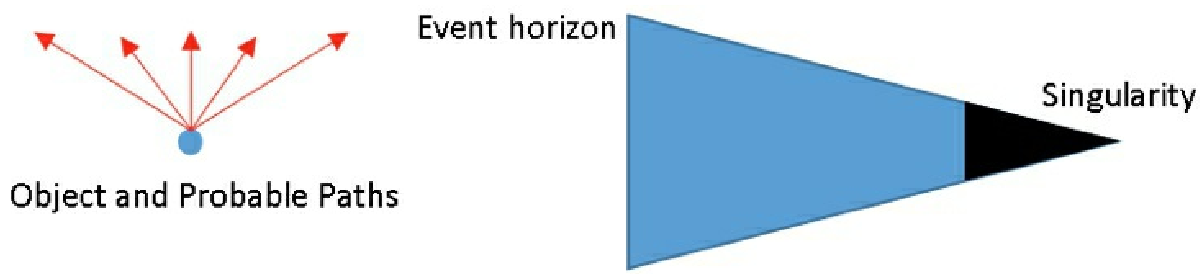
The event horizon is the boundary in spacetime. It is said that any event inside the event horizon cannot affect an observer from outside the boundary. This boundary can also be taken as the surface of the black hole. Beyond the black hole, the gravity becomes so strong that nothing may ever come out of it, so physics also dubs the event horizon as the *point of no return*. Therefore, any event that happens inside the event horizon will never reach the observer outside of it, including the information about that event.

General relativity states that an object with mass deforms space and time immediately around it. This results in the path of the particles around that mass to bend towards that mass. Outside the event horizon, the particles can move in any direction. Inside the black hole, the paths being followed by the particles are so bent that there are no paths leading away from the black hole.

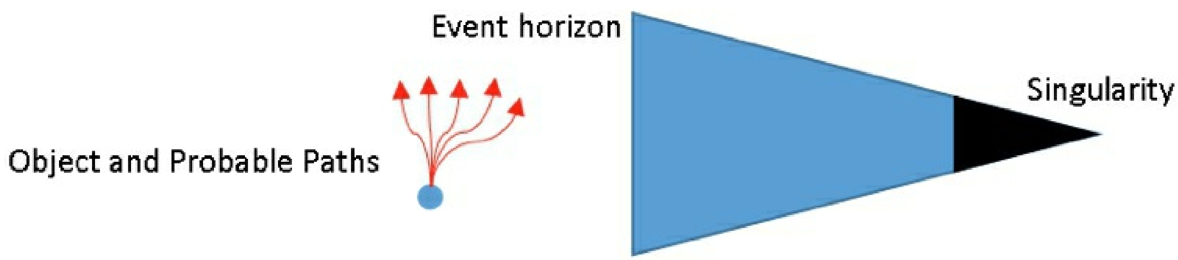
How a Black Hole Distorts Space and Time in Its Surroundings

A black hole has effects over a particle or object. The perceived effects are provided theoretically and are based upon the generally accepted theory of general relativity.

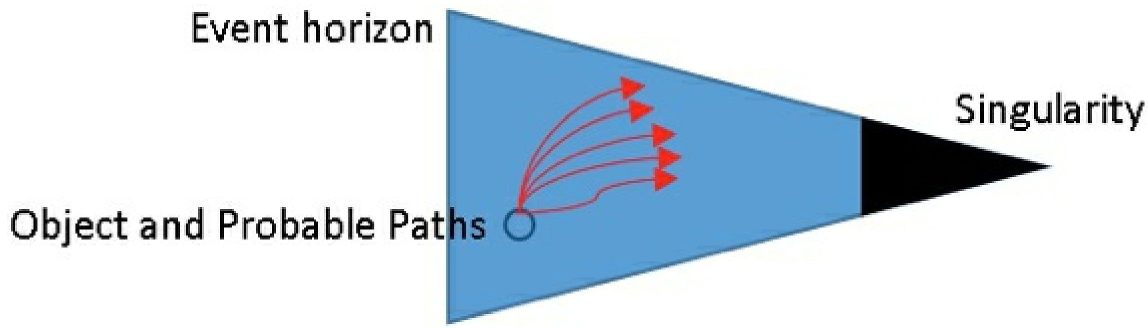
Case 1 – The path of the particle with a significant distance from the black hole:



Case 2 – The path of a particle as it comes closer to the event horizon:



Case 3 – The path of the particle when it has breached the point of no return:



Object Falling Into a Black Hole

Based on general relativity, there is a phenomenon called gravitational time dilation. In this phenomenon, observers would see a clock near a black hole ticking slower than clocks away from the black hole. Because of this phenomenon, an object falling into a black hole would appear to slow down as it reaches the event horizon in an infinite amount of time. Internal processes in this object also slow down. This slow motion of the object would emit light that would appear redder and dimmer to an outside fixed observer. This phenomenon is called gravitational redshift. This object will eventually become so dim that it can hardly be seen as it reaches the event horizon.

An Observer Falling Into a Black Hole

If an observer falls into a black hole, the observer will not notice any of the effects described as he reaches the event horizon. What an observer can do, though, is to calculate the time that he crosses the event horizon, but he will still not notice any singular behavior or special feeling. The observer will not even notice the point when he crosses the event horizon, as it is impossible to tell the exact location of the event horizon from that vantage point.

Chapter 4 – Anatomy: Schwarzschild Radius

The Schwarzschild radius or the gravitational radius is the area bound by the event horizon and with a gravitational pull so strong the escape velocity is equal to the speed of light. Astrophysics defines the Schwarzschild radius as the radius of a sphere that when all the mass of an object is compressed in that sphere, the resulting escape velocity would equal the speed of light.

German physicist Karl Schwarzschild based his solution on Einstein's field equations.

$$r_s = \frac{2Gm}{c^2}$$

Where:
r_s = Schwarzschild radius
G = Newton's Gravitational constant
m = mass of the object
c = speed of light in vacuum

The Schwarzschild radius represents the ability of an object with mass to cause a curvature in space and time.

Black Hole Classification Based on Schwarzschild Radius

Black holes are classified according to the Schwarzschild radius.

1. **Supermassive Black Hole (SMBH)**

    This is the largest type of black hole. Most scientists infer that these types of black holes are found in the center of galaxies, including our very own Milky Way.

    SMBH have distinct properties such as an average density that is lower than that of water.

SMBH accumulate matter at normal density; hence, the Schwarzschild radius increases faster than the radius. This accumulation would fall within the Schwarzschild radius of 150 solar masses.

Super massive black holes may have formed due to the accumulation of other masses and other stellar black holes.

2. **Stellar Black Hole (Collapsars)**

   Stellar black holes accumulate matter at nuclear density. This kind of accumulation would result in a Schwarzschild radius with 3 to several tens of solar masses.

   They are formed by the collapse of a massive star and are observed as hypernova explosions. Black holes that were naturally formed have angular momentum (spin). The spin may have been the residual spin of the star that formed it.

3. **Primordial Black Hole**

   Primordial black holes were thought to have been formed during the early life of the universe, back when densities were too high.

   It was presumed that during the Big Bang, temperature and pressure were so high that some regions with dense matter formed into black holes. Because of the rapid expansion of the then young universe, such regions of high density may have easily dispersed, but not so with primordial black holes. Scientists believe that they were stable and could still presently exist.

Time and Space inside the Schwarzschild Radius

At the Schwarzschild radius, radial distance intervals become infinite and time passes slowly. This is like the values of both space and time becoming imaginary.

The analysis of the Schwarzschild radius used to have a problem in terms of the observer being at rest. It was eventually solved that inside the Schwarzschild radius, nothing is at rest because everything falls into the singularity.

Chapter 5 – Anatomy: Singularity and the Spherical Effects

Singularity

The gravitational singularity is found at the center of the black hole. In this area, the space time curvature becomes infinite. The singularity takes the shape of a point in space in a non-rotating black hole and a distributed ring of singularity in the case of a rotating black hole. The singular region has zero volume but has all the mass of the black hole. Based on this, we can compute that the singular region has infinite density.

Falling Inside a Rotating Black Hole

Charged (Reissner-Nordström) black holes or rotating (Kerr) black holes are thought to be warps (hypothetically) that can land you in a different spacetime, like a wormhole. This is because the rotation of the black hole offers a way to avoid the singularity, hence avoiding destruction.

This warp-like phenomenon is only theoretical and is yet to be proven. Most theoretical scientists believe that any chance of proving this is difficult because any unpredictable event inside the black hole could mean destruction. Also, such an unpredictable event is most likely to happen because of the extreme conditions inside the singularity.

Falling Inside a Non-Rotating Black Hole

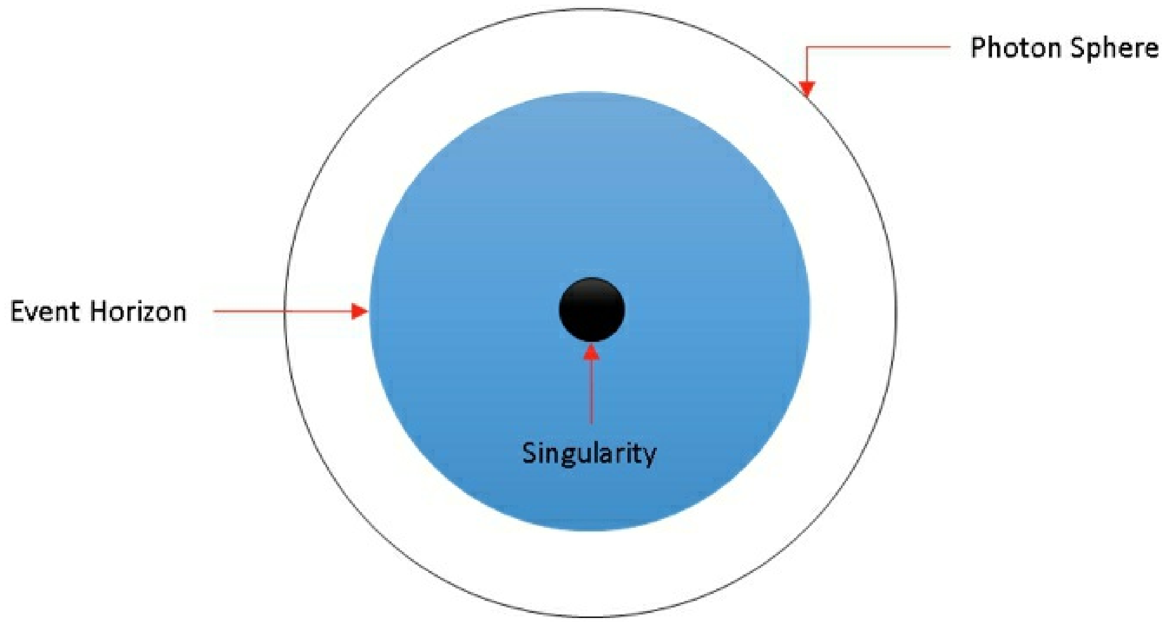
Unlike rotating black holes, Schwarzschild black holes offer no possibility of escaping the singularity. It is possible, however, to prolong the impact by accelerating away from the singularity.

Upon contact with the singularity, an object is crushed and is added into the mass of the black hole.

Rules of Physics in Singularities

In the singularity, the rules of physics break down. This is because of the infinite density low volume nature of the singularity where time and space are broken down.

Photon Sphere in Black Holes



Photon spheres are boundaries in space where the gravity is so strong that photons tend to orbit around them. A photon sphere's thickness is zero and it is highly unstable that any disturbance in the system can cause it to collapse and breach the event horizon or scatter it and escape the black hole's gravity pull.

Photon spheres are thought to be one and a half times the Schwarzschild radius. Here are some of the photon sphere's significant characteristics:

1. **Centrifugal Force Reversal**

   The distinct characteristic of the photon sphere is the reversed effect of the centrifugal force. Normally, the centrifugal force is strong when the revolution speed is high. On the photon sphere, however, the centrifugal force drops to zero. Inside the photon sphere, the centrifugal force becomes negative. That means the faster an object orbits, the greater the inward force.

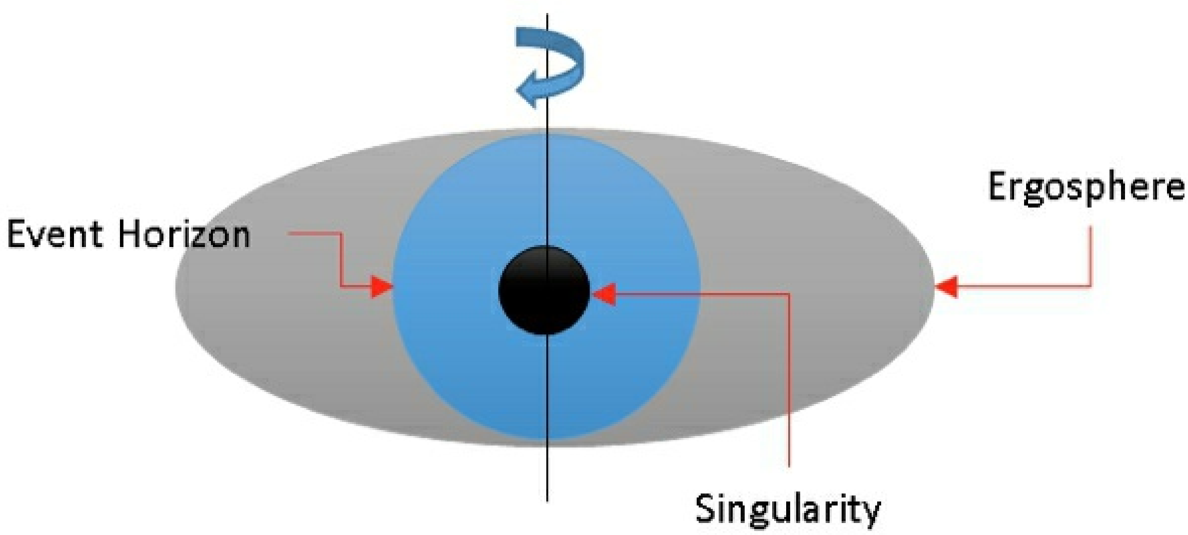
2. **Accelerating In and Out**

   Any object falling into the photon sphere will most certainly breach the event horizon but any object coming from the inside of the photon sphere may exit the black hole's gravitational pull. It is also assumed that an object can skim or hover above the event horizon if it can maintain its acceleration.

3. **2 Photon Spheres**

   Rotating black holes have 2 photon spheres. The first one is nearer the black hole while the second one is farther out. The first photon sphere rotates in the same direction as the black hole while the second one rotates in the opposite direction. The creation of two photon spheres only holds true when the approach to the black hole is to the equator. If approached at a different angle, only one photon sphere can be created.

Ergoshere in Black Holes



The ergosphere is a region around a rotating black hole wherein staying at one point is impossible. The ergosphere is oblate spheroidal in shape with the polar radius being the shortest and the equatorial radius being the longest.

The ergosphere marks the area where the black whole drags spacetime in the direction of its rotation faster than the speed of light. Because of this effect, objects inside the ergosphere tend to be always moving relative to rest of the universe.

A layer called the static surface binds the ergosphere. Through general relativity, any rotating mass can drag spacetime in its immediate surroundings. This means that any object within its immediate vicinity will also tend to follow the direction of rotation of that mass. In black holes, this dragging effect is so strong that it would take an object to travel at the speed of light in the opposite direction of rotation to escape its force.

Since the ergosphere is still outside the event horizon, objects, which are inside the ergosphere, can still escape the black hole. This can be done by travelling with the black hole's rotation and then escape. Doing this will result in the object having more energy than it did when it entered the ergosphere. The process of removing energy from the black hole is called the Penrose effect.

The Penrose effect is thought to be the source of gamma ray bursts. When the Penrose effect happens, the ergosphere disappears and the black hole loses its rotation. Based on mathematical models, as much as 29% of the energy from the rotating black hole is transferred to the escaping object.

Chapter 6 – Evidence and Other Issues

So how is a black hole detected? Light can't escape from it, so technically it is invisible. This was the confounding question most researchers have grappled with ever since Einstein first presented general relativity.

Through the years, several evidences have been discovered and presented to detect black holes.

Ways of Detecting Black Holes

1. **Hawking's Radiation**

   According to Stephen Hawking's argument in 1974, black holes emit certain traces of thermal radiation. According to Hawking, this radiation reduces the mass and energy of the black hole and is sometimes called evaporation. It is thought that black holes that emit more radiation than they accumulate mass are more likely to vanish.

2. **Monitoring of Accretion Discs**

   Accretion discs are usually found around a central body and are usually made up of diffuse material. The gravity in the massive central body causes the accretion disc to orbit and spiral inwards.

   Since accretion discs are made of diffuse materials, they tend to rub and compress against each other due to gravitational forces. This results in an increased temperature in the disc and the emission of electromagnetic rays such as X-rays. It is the electromagnetic rays that the telescopes aim to detect.

   It is thought that some of the high-energy phenomena in the universe are reportedly due to accretion discs.

3. **Binary Star Systems**

It is thought that some stars rotate around another star. However, some stars are detected without companions but are seen in X-ray emissions as having a companion. These kinds of binary systems are what scientists are focused on. Stars which do not seem to have a companion are more likely to have black holes as a companion.

4. **Gravity Lens**

    General relativity states that gravity can bend space. This was proven when a distant star's position was measured during a solar eclipse. It was seen that the star's position shifted because the sun bent the light coming from that star. Hence, when the Hubble Space Telescope sees a distant star as two objects too close together with the object bending space being unseen, then there's a possibility that it was a black hole.

Information Loss Paradox

Since majority of what we know about black holes is through theoretical physics, a few lingering issues still persist. One of them is the conservation of matter, more specifically, the information about that matter.

Take for example a tennis ball that was dropped into the black hole. Since the black hole only has a few known parameters (mass, charge and angular momentum), it seems that other information regarding that tennis ball is lost.

If black holes remain forever, then it is easy to assume that the information remains inside the black hole and is not lost—only inaccessible.

However, black holes evaporate and produce Hawking radiation. Hawking radiation does not have any information on any matter that has been engulfed by the black hole. Hence, it seems the information is lost forever.

This issue has been a problem among theoretical physicists and is up until now being studied and approached in different fronts. The advancement on full quantum gravitational theory may solve this issue but the results are still in the initial stages.

Conclusion

Thank you again for downloading this book and I hope you learned lots about black holes and find them as fascinating and mysterious as I do.

Finally, if you enjoyed this book, please take the time to share your thoughts and post a review on Amazon. It'd be greatly appreciated!

Thank you and happy (space) travels!

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